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THE STRUCTURES OF VERMICULITES AND THEIR COLLAPSE BY DEHYDRATION

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INTRODUCTION

The question whether vermiculites are distinct minerals has puzzled mineralogists for many years. A number of attempts have been made to find definite type formulas for them. Often they have been considered as "hydrated micas." It will be shown in the following pages that this idea comes very close to the truth, and that a vermiculite is a definite mineral species with a definite crystal structure. If, however, a so-called vermiculite contains alkalies to an appreciable extent a type of mineral results which is neither a vermiculite nor a mica but an "interstratification" of unit layers of these two. The *x*-ray diagrams for this type are different from either of the other two.

Preliminary and necessary for the investigation of the vermiculites was the knowledge of the structures of the micas as described by Pauling,[1] and Jackson and West;[2] of the chlorites by Pauling[3] and McMurchy;[4] and of the kaolin group by the writer.[5] The structures of talc and pyrophyllite, suggested by Pauling[6] and lately worked out by the writer,[7] were also of great importance in the correct interpretation of the vermiculites.

In obtaining material for *x*-ray analysis the writer is especially indebted to Dr. C. S. Ross of the U. S. Geological Survey, and Dr. W. F. Foshag of the U. S. National Museum who supplied most of the specimens listed below.

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[1] Pauling, Linus, *Proc. Nat. Acad. Sci.*, vol. **16**, pp. 123–129, 1930.

[2] Jackson, W. W., and West, J., *Zeit. f. Krist.*, vol. **76**, pp. 211–227, and vol. **85**, pp. 160–164, 1933.

[3] Pauling, Linus, *Proc. Nat. Acad. Sci.*, vol. **16**, pp. 518–582, 1930.

[4] McMurchy, R. C., *Zeit. f. Krist.*, 1934, vol. **88**, pp. 420–432, 1934.

[5] Gruner, J. W., *Zeit. f. Krist.*, vol. **83**, pp. 75–88, 1932; vol. **83**, pp. 393–404, 1932; vol. **85**, pp. 345–354, 1933.

[6] *Proc. Nat. Acad. Sci.*, vol. **16**, p. 126, 1930.

[7] *Zeit. f. Krist.*, 1934, vol. **88**, pp. 412–419, 1934.

CHEMICAL DATA

The following twelve specimens were examined. Their chemical analyses are given in Table I.

Specimen No. 1. Vermiculite from Bare Hills near Baltimore, Md. E. V. Shannon: *Am. Jour. Sci.*, vol. **15**, p. 21, 1928. Pale yellow-green scales resembling talc. Catalogue No. 95647 of U. S. Nat. Museum.

No. 2. "Protovermiculite" from Magnet Cove, Ark. F. W. Clarke and E. A. Schneider: *Am. Jour. Sci.*, vol. **42**, p. 242, 1891. Large golden yellow books or scales. Only very little exfoliation. Sp. grav. = 2.05–2.10.

No. 3. "Lucasite" from Corundum Hill, North Carolina. Th. M. Chatard: *U. S. Geol. Surv.*, *Bull.* **42**, p. 51, 1887. Yellowish brown, scaly. Catalogue No. 88507 of U. S. Nat. Museum.

No. 4. Vermiculite from Wiant's Quarry near Pilot, Md. C. S. Ross, E. V. Shannon and F. A. Gonyer: *Econ. Geol.*, vol. **23**, p. 542, 1928. Yellowish brown, compact, scaly aggregate. Talcose feel. Sp. grav. = 2.31.

No. 5. Vermiculite from Webster, North Carolina. *Idem*, p. 536, Table 3, Analysis 4. Greenish yellow scales.

No. 6. Vermiculite from Webster, North Carolina. *Idem*, Table 3, Analysis 1. Fine, greenish yellow scales.

No. 7. Nickeliferous vermiculite from Webster, North Carolina. C. S. Ross and E. V. Shannon: *Am. Mineralogist*, vol. **11**, p. 92, 1926. Apple green, small scales. Catalogue No. 95487 of U. S. Nat. Museum.

No. 8. "Jefferisite" from Brinton Quarry, West Chester, Pennsylvania. F. W. Clarke and E. A. Schneider: *Am. Jour. Sci.*, vol. **40**, p. 452, 1890. Brownish black large plates. Sp. grav. = 2.35. Exfoliates easily.

No. 9. So called "vermiculite" from Libby, Montana. Commercial analysis by U. S. Bureau of Standards, Washington, supplied by C. S. Ross. Very dark greenish brown scales. Sp. grav. = 2.64. Exfoliates readily. Note the discrepancy in the analyses of the alkalies.

No. 10. So called "vermiculite" from unknown locality. Brownish black large plates. Sp. grav. = 2.49. Exfoliates easily.

No. 11. "Chloritic vermiculite" from Old Wolf Quarry, Chestnut Hill, Easton, Pa. Described by G. P. Merrill in *U. S. Geol. Surv.*, *Bull.* **90**, p. 19, 1892. Light yellowish green, scaly, talc-like. Does not exfoliate appreciably. Catalogue No. 70118 of U. S. Nat. Museum.

No. 12. "Vermiculite" from Corundum Hill Mine near Franklin, N. C. Unanalyzed. Collected by C. S. Ross. Brownish to greenish black large scales. Harder than other vermiculites.

Additional information including optical data for these minerals may be found under their respective references.

As in the micas the chemical analyses differ considerably. Based on x-ray diagrams specimens 1 to 7 belong to the same species which is here designated as *vermiculite*. Specimens 9 and 10 belong to a species for which the name *hydrobiotite* is proposed. This name

TABLE I. ANALYSES OF SPECIMENS USUALLY CLASSIFIED AS VERMICULITES

	1	2		3	4	5	6	7	8		9		10	11
SiO_2	36.12	34.03		32.97	35.92	36.54	34.92	34.76	34.20		41.0			43.71
TiO_2	0.24						0.60							
Al_2O_3	13.90	14.49		17.88	10.68	16.96	13.06	14.86	16.58		18.0			3.59
Fe_2O_3	4.24	7.71		4.76	10.94	2.78	2.74	2.74	7.41		7.0			0.90
FeO	0.68	0.14		0.57	0.82	0.95	0.54	0.41	1.13					
NiO	0.28				none	2.32	3.24	11.25						
MnO	trace	0.09		trace										
MgO	24.84	20.89		22.36	22.00	19.78	23.92	18.18	20.41		21.0			38.58
CaO	0.18	1.88		none	0.44	0.06	0.24	0.40			1.0			
K_2O		———		none						1.87*	1.0	5.86*	3.70*	2.22
Na_2O										0.14*		0.11*	0.18*	0.13
Total H_2O	18.94	21.19		21.47	19.84	20.40	20.30	17.80	21.14		11.0		12.06*	11.25
	99.42	100.42		100.01	100.64	99.79	99.56	100.40	100.87		100.0			100.38
H_2O–110°	(−130°) 8.20	7.28	19.16*	11.42	10.50	9.24	9.00	(−120°) 5.20		15.44*			4.63*	0.46
H_2O 110°–400°		(750°) 7.96			4.34	3.80	5.00							(−300°) 0.09
H_2O at red heat		3.92		10.05	5.00	7.36	6.30	12.60						10.70

* Analyses by R. B. Ellestad of powders actually x-rayed.

was used long ago by Schrauf[8] and others to designate biotite-like material high in water. Specimen No. 8 is a mixture of vermiculite and hydrobiotite since it gives both *x*-ray patterns. It will be observed that it contains 2% alkalies and less H_2O than typical vermiculite. No. 11 from Easton, Pa. cannot be classified at present, it has no characteristic vermiculite lines and may be a mixture of talc, chlorite and serpentine. No. 12 is a distinct mixture of biotite and vermiculite as it gives both diagrams.

TABLE II

	Average of analyses 1 to 7		Theoretical compositions
SiO_2	35.04	35.04	$36.71 = 22\ SiO_2$
Al_2O_3	14.55	14.55	$14.15 = 5\ Al_2O_3$
Fe_2O_3	5.13	5.13	$4.43 = Fe_2O_3$
FeO	0.59		
NiO	2.44		
MgO	21.71	25.20	$24.62 = 22\ MgO$
CaO	0.46		
H_2O	19.99	19.99	$20.09 = 40\ H_2O$
Total	99.91	99.91	100.00

To arrive at a working formula for vermiculite analyses 1 to 7 were averaged as shown in Table II. This formula has to be accommodated in the structure which as shown later consists of mica units, minus K_2O plus H_2O. Without the H_2O the structural formula would be $(OH)_2Mg_3(Si_3Al)O_{10}$ disregarding valencies. Remembering that Fe may replace Al or Mg, or both, and that more than 25% of Si may be replaced by Al the structural formula including H_2O may be expanded to $(OH)_2(Mg,Fe)_3(Si,Al,Fe)_4O_{10} \cdot 4H_2O$; or written in a different form, it becomes:

$$11(Mg,\ Fe)O \cdot 3(Al,\ Fe)_2O_3 \cdot 11(Si,\ Al)O_2 \cdot 20H_2O, \text{ or}$$
$$22MgO \cdot 5Al_2O_3 \cdot Fe_2O_3 \cdot 22SiO_2 \cdot 40H_2O.$$

The amount of H_2O in this formula is based on the average H_2O content in Table II. The fact that the number of H_2O molecules in this analysis is an even whole number makes it fairly certain, from the structural point of view, that it is correct. This formula is similar to that proposed by Ross and Shannon[9] which is $12MgO \cdot 3Al_2O_3 \cdot 12SiO_2 \cdot 19\frac{1}{2}H_2O$.

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[8] Schrauf, A., *Zeit. f. Krist.*, vol. **6,** p. 381, 1882.

[9] *Am. Mineralogist*, vol. **11,** p. 92. 1926.

It is, of course, obvious that K^+ cannot be removed from a mica and H_2O substituted without having negative charges left over. These must be neutralized either by oxidation of Fe^{II} to Fe^{III} or by introduction of H^+. Another possibility would be the substitution of F^- or OH^- for $O.^{--}$ Which of these processes are operative is impossible to say at present. Usually there will not be enough Fe^{II} present whose oxidation could neutralize the loss of K. It is commonly thought that Fe^{III} occupies Al positions. This is not so likely in the vermiculites for the Al occupies chiefly Si positions in the $Si_3Al\ O_{10}$ layers. The Fe^{II} is in Mg positions to begin with. There is no reason why Fe on oxidation should move into Al positions. There would be no vacancies anyway.

The hydrobiotite analyses, 9 and 10, and 8 which is partly hydrobiotite, contain considerable amounts of alkalies. The *x*-ray diagrams show clearly that these minerals are made up of interstratified single or double layers of units of mica (M), and vermiculite (V). The interstratifications which exist in them can be at least two-fold both agreeing with *x*-ray data. They are: M-V-M-V- and V-V-V-M-M-V-V-V-M-M-. Other combinations of these layers are possible but become complicated. The formula for the first one would be:

$$(OH)_4K(Mg, Fe)_6(Si, Al, Fe)_8O_{20}.\ 4H_2O.$$

X-RAY DATA

On account of the physical nature of the material the powder method was used exclusively. Grinding of the samples in agate mortars distorted the structural planes to such an extent that no satisfactory diagrams could be obtained. All the samples were filed, therefore, unless received in crushed form, and screened through bolting cloth. The powder was mounted on silk thread with collodion. The thicknesses of the samples did not exceed 0.7 mm. A goniometer head was used for centering the samples in the circular camera (radius = 57.3 mm.). Cu radiation was found to be unsatisfactory on account of its marked absorption by minerals containing iron. Fe radiation ($K_\alpha = 1.9321$Å) was used instead. It gives very satisfactory results with sufficient time of exposure. Also, with the arrangement used for minimizing fogging by the zero beam it was possible to record the reflections of planes with spacings greater than $d = 14$Å. This is essential since reflections of planes with large d are of greatest importance in interpreting the diagrams. A self-rectifying gas tube with an output of about 7 to 9 Ma at 35 Kv was used.

TABLE III. POWDER DIAGRAMS

No.	1.		2.		3.		4.	
	d	*I*	*d*	*I*	*d*	*I*	*d*	*I*
1	13.4Å	8	13.6Å	9	13.7Å	9	13.6Å	10
2	7.03	1						
3	4.75	1	4.68	1				
4	4.45	1 *i*	4.41	0.5 *i*	4.43	1 *i*	4.43	2 *i*
5	3.91	1	3.88	1 *i*			3.91	1
6	3.537	4	3.537	3	3.548	3	3.541	4
7	3.126	1	3.129	0.5	3.104	1	3.137	1
8	2.838	3	2.838	3	2.852	3	2.840	5
9	2.6	1 *i*	2.630	1	2.630	1	2.620	2
10	2.521	2 *b*	2.535	1 *b*	2.526	1 *b*	2.530	2 *b*
11	2.366	4	2.375	3	2.375	3	2.372	4
12							2.256	0.5
13	2.192	1	2.182	0.5	2.193	1	2.192	1
14	2.129	0.5						
15	2.069	0.5	2.052	1	2.068	1	2.068	1
16	2.035	1			2.038	1	2.033	1
17	2.002	0.5	2.002	1 *b*	2.000	1	2.005	1
18	1.833	1	1.816	0.5	1.836	1	1.836	1
19	1.774	1						
20	1.732	0.5	1.732	0.5	1.733	0.5	1.730	1
21	1.664	2	1.657	1 *b*	1.668	3	1.670	3
22	1.584	0.5			1.585	0.5	1.588	0.5
23	1.570	0.5			1.571	1	1.573	1
24	1.526	4	1.530	4 *b*	1.527	3 *b*	1.526	6 *b*
25	1.496	1					1.500	0.5
26	1.462	0.5					1.465	0.5
27	1.441	2	1.432	1 *b*	1.441	2	1.445	2
28	1.429	1			1.428	1	1.433	1
29	1.352	1	1.348	0.5	1.354	0.5	1.353	1
30	1.321	3			1.328	3	1.330	3
31	1.312	1	1.314	2 *v.b.*	1.314	1		
32	1.289	1	1.290	0.5	1.291	1		
33	1.270	1			1.271	0.5		
Spacing of d_{001}=	28.42		28.38		28.50		28.46	

i = indistinct edge of line.
b = broad line.
v.b. = very broad line.
β = a line produced by Kβ radiation of iron.

OF VERMICULITES. Fe RADIATION

5.		6.		7.		Indices
d	*I*	*d*	*I*	*d*	*I*	
13.7Å	10	13.6Å	10	13.6Å	10	002
		7.04	0.5	7.12	5	004
		4.71	1			006
4.48	1 *i*	4.39	1 *i*	4.45	2 *b*	
3.90	1	3.92	1	3.94	1 *b*	008β
3.540	3	3.548	4	3.562	5	008
3.126	1	3.145	1	3.162	0.5 *i*	0010β
2.833	4	2.847	5	2.847	1 *i*	0010
2.609	2			2.6	1	$130,\ 20\bar{2},\ 13\bar{2},\ 200$ and
					i v.b.	$13\bar{6}\beta,\ 204\beta$
2.524	3 *b*	2.537	1 *v.b.*	2.48	3	$132,\ 20\bar{4},\ 13\bar{4},\ 202$
2.367	4	2.379	3 *b*	2.380	1 *b*	$13\bar{6},\ 204$
2.253	0.5					$136,\ 20\bar{8}$
2.185	1	2.188	1 *b*	2.133	0.5 *i*	$206,\ 13\bar{8}$
2.059	1	2.069	1			$20\overline{10},\ 138$
		2.035	1			0014
1.998	1 *b*	2.002	1			$13\overline{10},\ 208$
1.828	1	1.833	1			$13\overline{12},\ 2010$
						0016
1.726	1	1.735	1	1.739	0.5 *i*	
1.661	3 *b*	1.668	2 *b*	1.676	2 *i*	$13\overline{14},\ 2012$
						$1316\beta,\ 20\overline{18}\beta$
1.569	0.5	1.568	0.5 *b*			$0018,\ 1314,\ 20\overline{16}$
1.524	5 *b*	1.530	3 *b*	1.526	6 *b*	$060,\ 33\bar{2},\ 330,\ 33\bar{4},\ 13\overline{16},\ 2014$
1.498	0.5	1.500	0.5	1.494	2 *b*	$332,\ 33\bar{6}$
1.439	2	1.442	1	1.441	0.5 *i*	$1316,\ 20\overline{18}$
1.425	1	1.429	1			0020
1.349	0.5	1.354	0.5			$338,\ 33\overline{12}$
1.324	2	1.329	3			$1318,\ 20\overline{20}$
1.312	2	1.316	1		1	
1.288	1	1.292	1	1.300	*i v.b.*	0022
1.268	1	1.276	0.5 *i*			
28.38		28.46		28.56		

Table III contains the powder diagrams of the seven vermiculites. Lack of space does not permit the giving of distances measured in mm. in the films and their corresponding Θ angles. Intensities *I* are estimated visually. No correction except for thicknesses of samples were applied. On account of a slight eccentricity of the camera, and other factors, readings above 3.0Å are not as accurate as below that figure, especially is this true if they approach the zero beam. For the calculations of the unit cells only planes with *d* smaller than 3Å were used. These are quite accurate as found by comparison with standard substances. Some of the vermiculites give much sharper *x*-ray patterns than others. The least satisfactory lines were found in nickeliferous vermiculite No. 7. Some of its lines could not be recorded with certainty.

Table IV. Powder Diagrams of Minerals Formerly Designated as Vermiculites

No.	8.		12.		9.		10.		11.		Indices
	d	*I*	*d*	*I*	*d*	*I*	*d*	*I*	*d*	*I*	
1	13.6	8	14.1	8							002 *V*
2	11.6	2			11.4	5 *b*	11.6	6 *b*			002 or 005 *h*
3			10.02	1							002 *m*
4			6.98	0.5					6.93	8	004 *c* and *V*
5			4.70	1							
6	4.47	1	4.50	1 *i*	4.48	1 *i*	4.48	1 *i*	4.47	2 *i*	
7			3.92	1 β					3.95	2 β	008 β*c*
8	3.53	3	3.56	3					3.55	7	008 *V* and *c*
9	3.43	3			3.39	4 *b*	3.42	3 *b*			007 or 0018 *h*
10			3.334	2					3.29	2	006 *m*
11			3.143	0.5β							0010β *V*
12					3.071	0.5			3.066	1	006 *t*
13									2.919	0.5	
14	2.833	2	2.854	4	2.873	1β	2.859	1 β			0010 *V*
15									2.755	1	
16	2.609	4	2.636	3	2.596	5	2.601	4	2.619	2	
17			2.551	2 *b*							*m*
18	2.521	1 *b*	2.535	0.5							
19									2.434	4	*t* and *c*
20			2.384	3 *b*	2.394	3 *b*	2.395	2	2.391	2	

TABLE IV (*Continued*)

No.	8.		12.		9.		10.		11.		Indices
	d	*I*	*d*	*I*	*d*	*I*	*d*	*I*	*d*	*I*	
21	2.366	3 *b*					2.367	1 *b*			
22	2.241	0.5	2.256	0.5	2.220	1 *b*	2.252	0.5			
23	2.162	1	2.173	1 *b*	2.166	2 *b*	2.166	1.*b*			
24	2.058	0.5	2.075	1					2.125	3 *b*	
25			2.005	2 *b*	2.016	2	2.006	1	1.996	3	
26	1.918	1	1.918	0.5							
27	1.826	0.5	1.836	0.5β	1.842	0.5β	1.833	0.5β	1.847	0.5β	
28									1.809	2	
29									1.785	2	
30	1.723	1	1.734	1	1.734	0.5	1.725	0.5			
31	1.658	2 *b*	1.670	3 *b*	1.668	3 *b*	1.662	2 *b*	1.657	2 *b*	
32			1.566	0.5							
33	1.524	5	1.533	5	1.533	7	1.524	4	1.529	3	060 and others
34					1.517	0.5			1.492	3	
35			1.443	1	1.437	0.5			1.445	1	
36	1.426	0.5	1.429	1			1.425	0.5			
37	1.392	0.5			1.401	0.5	1.394	0.5	1.407	1	
38			1.357	1	1.346	0.5	1.339	1	1.357	2	
39			1.328	2	1.322	3					
40	1.312	1 *v.b.*	1.315	1			1.317	1			
41	1.288	1	1.292	1	1.298	1	1.289	1	1.301	2	
Spacing of d_{001}	28.38 and 24.0		28.50 and 20.02		23.7 to 24.2		24.0		?		

V = reflection of vermiculite.
h = reflection of hydrobiotite.
m = reflection of mica.
t = reflection of talc.
c = reflection of chlorite.

Since these minerals are certainly composed of layer structures similar to the micas and chlorites, the possible reflections from the basal planes should be rather prominent and easily identified. This is the case as may be seen in the tables III, IV, and VII. These reflections are especially sharp and conspicuous when the samples are mounted on thread because the cleavage particles align themselves parallel to the thread and give observed intensities 3 to 4 times as great as calculated. This was explained by the writer in a paper on dickite.[10]

It is a curious fact that the x-ray diagrams of powders heated to 110° C. for 24 hours do not show any changes, though very considerable amounts of water are driven off at 110° C. as shown in Table I. Specimens 1, 2 and 10 were x-rayed after this treatment. Heating for 5 to 24 hours at 750° C. produces new diagrams which are the result of the collapse of the structures in a direction normal to the basal cleavage.

INTERPRETATION OF X-RAY DATA OF VERMICULITE

The first step in the interpretation of the diagrams was to compare them with those of micas, chlorites, the kaolin minerals and talc. Certain striking similarities are noticed if the basal plane reflections are disregarded. No detailed account can be given of them in this place. Suffice it to state that the width b_0 of the unit cell of any of these structures is always given approximately by a strong line, examples, No. 24, Table III and No. 33, Table IV.[11] The dimension a_0 of the unit cell in the direction of the a axis can be computed from this reflection since the layer lattices are made up of hexagons.[12] Recalculations for greater accuracy of these dimensions are carried out after the indices for most reflections have been determined.

The most important clue to the structure was found when it was realized that vermiculite on dehydration at 750° C. gave a diagram almost identical with that of talc as shown in Table V, which contains the talc diagram and its indices as far as it concerns the present discussion, the only differences are that the basal reflections and most of the others are more diffused and broader than in talc proper.[13] This great similarity is also noticed in other properties of the dehydrated material. The scaly particles have a talcose feel and even look like talc in iron poor varieties. At this stage of the investigation the structures of talc and pyrophyllite were determined.[14]

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[10] *Zeit. f. Krist.*, vol. **83**, p. 395, 1932.

[11] The distance d must be multiplied by 6 since the reflection 060 is the 6th order of the plane 010; d of $010 = b_0$.

[12] See papers on mica and kaolinite.

[13] An explanation for this diffusion is to be found in the smaller grain size of individual particles after heating. They become too small for optimum reflective power.

[14] *Op. cit.*

Table V. Powder Diagrams of Vermiculites after Heating 24 Hours at 750° C. Fe Radiation

No.	1.		2.		3.		4.		5.		6.		7.		Talc		Indices
	d	*I*	*d*	*I*	*d*	*I*	*d*	*I*	*d*	*I*	*d*	*I*	*d*	*I*	*d*	*I*	
1	9.24	2	9.40	3 *i*	8.97	2	8.97	4	9.17	3	9.16	2	9.32	3	9.260	4	002
2	4.48	1 *i*	4.49	2	4.43	0.5 *i*	4.48	2 *i*	4.54	2	4.38	1 *i.b.*	4.43	2	4.53	3 *b*	6 planes
3															4.41		
4	3.84	0.5 *i*	3.90	1 *i*			3.8	1 *i*	3.83	1 *i*	3.93	1 *i.b.*	3.87	1	3.83	1 *v.b.*	6 planes
5					3.323	0.5	3.298	1	3.38	0.5 *i*							006β, 113
6	3.021	3	3.013	2 *i.b.*	3.016	4	2.985	4	3.036	3 *b*	2.997	2 *b*	2.95	0.5	3.086	5	006
7	2.859	1	2.875	1			2.875	1	2.859	1	2.861	0.5					$20\bar{2}\beta$, 130β
8	2.739	1 *i*	2.7	0.5 *i*			2.714	1	2.731	0.5	2.722	0.5					$20\bar{4}\beta$, 132β
9	2.609	1	2.614	2 *b*	2.597	1 *b*	2.584	3 *b*	2.596	3 *b*	2.607	1 *b*	2.61	1	2.613	1 *b*	$20\bar{2}$, 130
10															2.578		$13\bar{2}$, 200
11	2.444	3 *b*	2.459	3 *b*	2.462	2	2.447	4	2.455	4 *b*	2.459	2 *b*	2.44	1 *b*	2.447	5	$20\bar{4}$, 132
12	2.274	0.5															
13	2.198	1	2.188	1	2.185	1	2.169	2	2.187	2	2.189	1			2.178	2	$20\bar{6}$, 134
14	2.090	1	2.075	1 *b*	2.083	1	2.075	2	2.080	1	2.082	1			2.089	1	$13\bar{6}$, 204
15	1.909	1	1.898	0.5 *i*	1.890	1	1.884	1	1.900	0.5	1.889	0.5			1.897	0.5	$20\bar{8}$, 136
16	1.735	2					1.723	0.5	1.727	0.5			1.733	0.5			
17			1.686	1	1.688	0.5	1.679	1	1.678	1 *b*	1.678	0.5			1.663	3 *b*	138
18	1.649	1 *b*			1.641	1 *b*	1.629	2 *b*	1.651	1 *b*	1.632	0.5 *b*	1.658	1	1.647	2 *b*	$20\overline{10}$
19	1.522	2 *b*	1.529	3 *b*	1.526	3	1.522	4	1.529	4	1.529	2			1.517	4	060, $33\bar{2}$
20	1.508	0.5	1.508	0.5 *i*	1.506	0.5	1.501	1	1.512	1	1.514	1	1.509	3	1.499	1	330, 062, $33\bar{4}$
21	1.471	0.5											all lines		1.453	1	
22					1.430	0.5							indistinct		1.440	0.5	
23	1.364	2 *v.b.*	1.352	1 *v.b.*	1.365	3 *b*	1.357	3 *b*	1.367	1 *v.b.*	1.362	1 *v.b.*	and broad		1.384	4 *b*	$13\overline{12}$, 2010
24	1.346	1															
25					1.320	0.5	1.316	1	1.320	1					1.307	1	260
26			1.297	0.5	1.298	1	1.295	1	1.299	1					1.289	2 *b*	$26\bar{4}$, 400
27							1.232	0.5									

Talc consists of units like mica with the alkali layers absent as pointed out previously.[15] If vermiculite dehydrates to a talc-like structure no other layers but those made up of volatile material can occupy the positions that are filled by the alkalies in mica. Obviously this must be mostly or entirely water. With this information it is possible to determine the entire structure. How these calculations are made has been described in previous papers.[16] Agreement between theoretical and observed intensities is reached in vermiculite when the shift of one layer over the adjacent is approximately 1/3 of the length of a_0 (expressed in degrees = 120°) parallel to the a axis but in the opposite direction from the shift in the micas, chlorites and talc, as shown diagrammatically in Fig. 1. The resulting β angle is $97°09' \pm 10'$. The atomic coordinates are given in degrees in Table VI.[17]

TABLE VI. ATOMIC COORDINATES OF C^6_{2h} FOR VERMICULITE. FOUR EQUIVALENT ATOMS FOR EACH POSITION

Atom	X	Y	Z	Atom	X	Y	Z
Mg_1	0°	0°	0°	O_6	−58	30	138.5
Mg_2	0	120	0	O_7	122	30	138.5
Mg_3	0	−120	0	O_8	32	120	138.5
O_1	−51	180	14	O_9	51	180	166
O_2	−51	60	14	O_{10}	51	60	166
OH_1	−51	−60	14	OH_2	51	−60	166
O_3	58	30	41.5	Si_1	143	0	34
O_4	−122	30	41.5	Si_2	−37	60	34
O_5	−32	120	41.5	Si_3	−143	0	146
				Si_4	37	60	146

Table VII contains the calculated theoretical intensities of important planes as compared with the average of the observed intensities of the first six diagrams of Table III. The dimensions for calculating the distances of Table VII were taken from the chlorite structure and are: $\beta = 97°8'40''$, $a_0 = 5.31$Å, $b_0 = 9.20$Å, $c_0 = 28.46$Å. The space group is C^6_{2h}. The average dimensions of vermiculites are slightly larger. For example, $c_0 = 28.66$Å on an average. Allowance must be made for these slight differences in comparing Table VII with III.

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[15] Gruner, J. W., *Am. Mineral.*, vol. **16**, p. 451 and Fig. 22, 1931.

[16] *Zeit. f. Krist.*, vol. **83**, p. 79 and p. 395, 1932.

[17] The space group relationship of mica and vermiculite, both in C $^6_{2h}$ is this: The principal or para-glide planes (Paragleitspiegelebene, component $= c/2$) of vermiculite are the clino-glide planes (component $= c/2 + a/2$) of mica. The direction of gliding in vermiculite differs only by about 2½° from that in mica in the same plane.

Most interesting is the fact that the H_2O occupies a very definite thickness in the unit cell. This is shown by the figures at the

TABLE VII. THEORETICAL AND OBSERVED INTENSITIES FOR TWO MOLECULES OF VERMICULITE. NO ALLOWANCE IS MADE FOR THE GLANCING ANGLE

Indices	*d*	Theoretical Intensity	Observed Intensity	Indices	*d*	Theoretical Intensity	Observed Intensity
002	14.12	451	10	$20\overline{14}$	1.707	0	
004	7.06	21	0.3	$13\overline{14}$	1.656	302	2.5
006	4.71	13	0.5	2012	1.656	151	
020	4.60	55	1	0018	1.569	34	0.5
008	3.530	137	3.5	1314	1.559	69	
0010	2.824	106	4	$20\overline{16}$	1.558	34	
130	2.650	25		060	1.533	205	4
$20\bar{2}$	2.650	13		$33\bar{2}$	1.533	412	
$13\bar{2}$	2.635	39	1	330	1.524	250	
200	2.634	18		$33\bar{4}$	1.524	164	
132	2.576	102		$13\overline{16}$	1.513	214	
$20\bar{4}$	2.575	53		2014	1.513	108	
$13\bar{4}$	2.534	302	1.5	332	1.498	35	0.5
202	2.533	151		$33\bar{6}$	1.498	36	
134	2.432	28		1316	1.428	405	1.5
$20\bar{6}$	2.431	13		$20\overline{18}$	1.428	203	
$13\bar{6}$	2.374	454	3.5	0020	1.412	62	1
204	2.373	219		$13\overline{18}$	1.389	0	
0012	2.353	13		2016	1.389	0	
136	2.250	27		338	1.347	67	0.5
$20\bar{8}$	2.249	14		$33\overline{12}$	1.347	61	
$13\bar{8}$	2.186	214	1	1318	1.314	405	2.5
206	2.186	103		$20\bar{2}0$	1.314	204	
138	2.058	92	1	0022	1.234	58	1
$20\overline{10}$	2.058	48					
0014	2.017	104	1				
$13\overline{10}$	1.996	57	1				
208	1.995	29					
1310	1.875	19					
$20\overline{12}$	1.875	11					
$13\overline{12}$	1.817	103	1				
2010	1.817	54					
0016	1.765	6					
1312	1.707	0					

bottom of Table III which give the heights of the unit cells measured normal to the base. If a single layer of talc (=9.26Å, the unit cell is double this height) is subtracted from a single layer of vermiculite (=14.23Å) the thickness of a water layer is found to be 4.97Å. Almost the same figure may be obtained by subtracting the mica unit in chlorite from the chlorite unit (14.12Å −9.28Å = 4.84Å). Therefore, the H_2O layer requires a slightly larger space than the so-called brucite unit $6Mg(OH)_2$ in chlorite. Expressed in another form, V of $6Mg(OH)_2 = V$ of $8H_2O$ in layer structures. It is not possible at present to assign definite geometrical positions to H_2O in these layers. Nor can an explanation be given for the

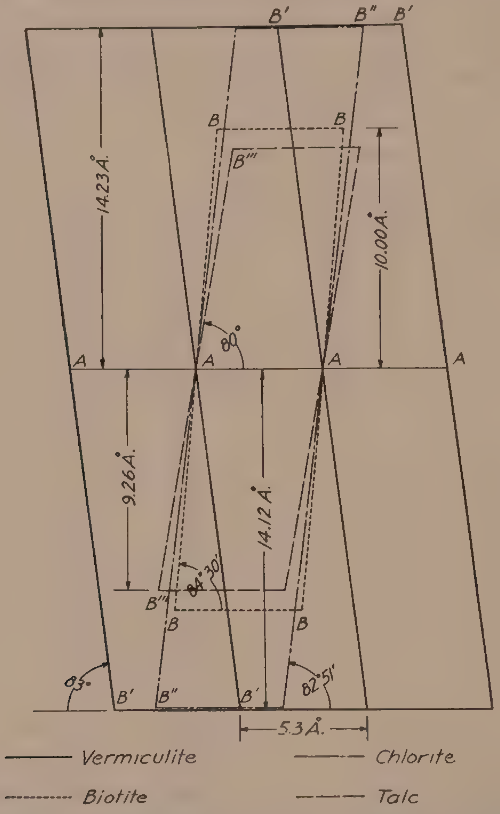

FIG. 1. Outlines of monoclinic unit cells of biotite, talc and chlorite superimposed on that of three unit cells of vermiculite. Plane of paper parallel to axial plane $a-c$.

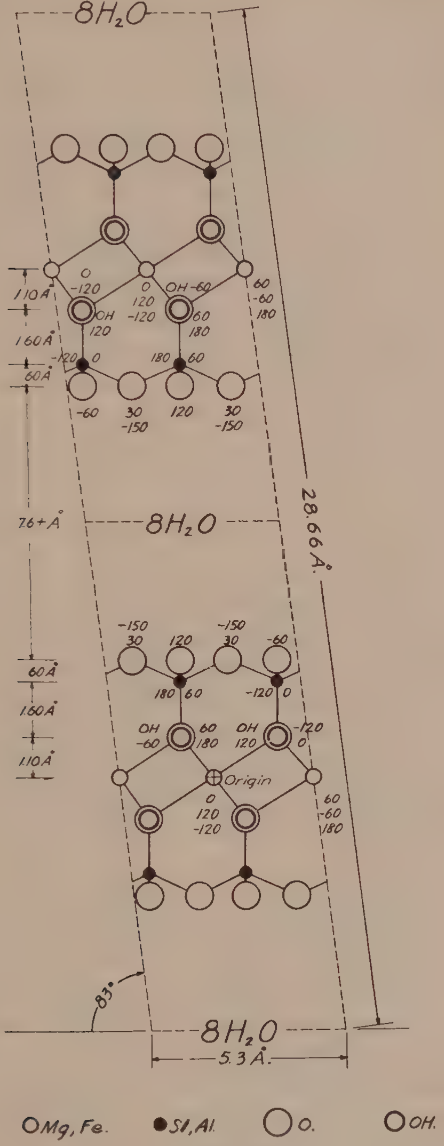

FIG. 2. Unit cell of vermiculite. The plane of the paper is the principal glide plane containing the origin of space group C^6_{2h}. The *y* coordinates parallel the *b* axis are given in degrees. The origin is also a center of symmetry.

gradual dehydration as the temperature is raised. About 4 per cent of the H_2O held as OH in the mica units should, however, be stable even at low red heat.

Figure 1 illustrates the relative movement which a given point in a certain structure undergoes in order to reach a corresponding position in a new structure. For example in the change from biotite to vermiculite: The points A-A-A-A are identical points in a given layer. This layer remains stationary during all changes. The points B-B of biotite represent identical points to each other (not to A) in a plane parallel to the plane of the paper. When the structure expands to vermiculite the points B move in this plane to their nearest new positions B'. B' positions are identical to B positions as far as single layers of the structures are concerned. On dehydration the B' positions move in the same plane to the nearest corresponding B''' positions of the talc structure. B'' positions are chlorite positions corresponding to B positions in mica.

INTERPRETATION OF X-RAY DATA OF HYDROBIOTITE

The diagrams of specimens 8, 9 and 10 in Table IV and their dehydrated products (Table VIII), presented puzzling features at first. The lines originating from basal reflections are broader and less agreement exists among them than in other similar structures. A number of different combinations of layers of vermiculites, micas, chlorites, brucite, and kaolinites were tried for unit cells and their basal reflections calculated. The same calculations were made for their dehydrated products. The only combinations that show any agreement with observed reflections are those listed under "Chemical data."

A stacking of alternate units of mica and vermiculite results in a unit cell 24Å or a multiple of 24Å high. Only two of its basal reflections, which are also the strongest theoretically, can be identified with certainty in the diagrams as lines 2 and 9. They have indices 002 and 007, respectively (Table IV). On dehydration such a unit cell shrinks to a height of 19.2Å or a multiple of it (the sum of a unit of mica and talc). Its two theoretically strongest basal reflections appear in Table VIII as lines 1 and 5 with indices 002 and 006 or its multiples, respectively.

The observed lines for hydrobiotite and its dehydrated material also fit a unit cell with a height of 62Å and 47.5Å respectively, which has a stacking of 3 vermiculite to 2 mica units in the manner given under chemical data, or in another combination, M–V–M–V–V–M–V–M–V–V–

It is not proposed that mica altering to hydrated material could do so only in ratios 1M:1V or 2M:3V, before it altered to vermiculite entirely. Probably all types of irregularities may and do exist. When distinct diagrams, however, are recognized as in 8, 9 and 10, such distinct compounds must make up a large part of the specimen. A specimen of commercial "vermiculite" from near Salida, Colo., was *x*-rayed. No distinctive *basal* reflections could be recognized. This may mean that the ratio of any definite constituent to the sum of the others is so small that it is insufficient

Table VIII. Powder Diagrams of Minerals Formerly Designated as Vermiculites After Heating 24 Hours at 750° C.

No.	8.		12.		9.		10.		Indices
	d	*I*	*d*	*I*	*d*	*I*	*d*	*I*	
1	9.40	3	9.67m	3	9.56	3	9.56	3	002 or 005
2	4.46	1 *i*			4.53	1 *i*	4.50	1 *i*	
3			3.64m	0.5β					
4					3.57	1β			
5	3.174	1 *i*	3.238m	3	3.239	3	3.160	1 *b*	006 or 0015
6	3.003	1 *i*							
7	2.861	1 β	2.861	0.5β	2.880	1 β	2.873	1β	
8	2.596	2	2.596	2 *b*	2.613	4	2.601	3	
9	2.424	2	2.413	1 *b*	2.431	3 *b*	2.423	2 *b*	
10			2.256	0.5					
11	2.155	1	2.154	1 *b*	2.171	2 *b*	2.161	1 *b*	
12	2.061	0.5							
13			1.983	1	1.971	0.5 *i.b.*	1.977	0.5 *i*	
14	1.881	0.5	1.892	0.5	1.903	0.5	1.882	1	
15			1.829	0.5β	1.837	0.5β			
16	1.674	1 *b*	1.655	1 *b*	1.668	2 *b*	1.679	1	
17	1.628	1 *i.b.*					1.648	1	
18	1.522	3	1.522	3	1.532	5	1.524	3	
19	1.507	1			1.514	1	1.506	1	
20			1.453	0.5	1.461	0.5β	1.452	0.5β	
21	1.351	1 *b*	1.350	1	1.363	1 *b*	1.353	2	
22	1.313	0.5	1.317	0.5	1.323	2	1.315	1	
23	1.293	0.5			1.296	1	1.290	1	

m = definite mica reflection.

for recording in the film, or that no definite unit cells, as far as the stacking of the layers is concerned, exist. No name has been suggested for such an heterogeneous arrangement of layers in one direction. The word *metacrystalline* is proposed to signify a state of partial change from one definite crystal structure to another without, however, attaining a homogeneous space group arrangement in one of the directions.

CONCLUSIONS

An x-ray study of analyzed vermiculite minerals reveals the following facts:

Vermiculite exists as a distinct mineral. Its structural formula is $(OH)_2(Mg, Fe)_3(Si, Al, Fe)_4O_{10} \cdot 4H_2O$. Its formula based on the average of seven true vermiculites is

$$22MgO \cdot 5Al_2O_3 \cdot F_2O_3 \cdot 22SiO_2 \cdot 40H_2O.$$

Fe^{II} which is oxidized in the change from mica to vermiculite probably continues to occupy its Mg positions in the structure. The loss of K^+ ions in this change is probably partly neutralized by the change of Fe^{II} to Fe^{III}.

The unit cell of vermiculite is monoclinic holohedral with the probable space group C^6_{2h}. $a_0 = 5.3 + Å$, $b_0 = 9.2 + Å$. c_0 varies between 28.57 and 28.77 Å in seven samples. $\beta = 97°09' \pm 10'$. The cell contains 4 molecules of the structural formula above. Its theoretical density is 2.13+.

The structure consists of $(OH)_4Mg_6(Si, Al)_8O_{20}$ sheets, like mica and talc, between which are interstratified layers of $8H_2O$ which occupy a space of definite thickness close to 4.9Å. Compared with the structure of the chlorites these $8H_2O$ occupy almost exactly as much space as the brucite layer $6Mg(OH)_2$ in chlorite. Though almost half of the H_2O may be driven off at 110° C. no essential changes occur in the powder diagrams of specimens treated in this manner.

On heating vermiculite to 750° C. a collapse to the talc structure occurs. The well known exfoliation on heating seems to be a simple mechanical disintegration of larger particles due to the formation of steam.

The old term hydrobiotite is used again to designate interstratification of "molecular" layers of biotite with vermiculite resulting in a new x-ray pattern. The word meta-crystalline is proposed for such an arrangement and signifies a perfectly normal space group arrangement in all but one direction. In the latter the sequence of layers or of units is heterogeneous to a certain extent. It may, however, as in specimens 9 and 10 approach a definite ratio of 1:1 = biotite units: vermiculite units.

X-ray diagrams are necessary to distinguish vermiculite from hydrobiotite.

SUSSEXITE FROM IRON COUNTY, MICHIGAN

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In 1930 seamanite, a new manganese phosphoborate was reported from the Chicagon Mine in Iron County, Michigan.[1] Associated with the seamanite, but occurring in thin veinlets from 1mm. to 3mm. wide, was a white to yellowish-buff colored mineral which upon subsequent examination was shown to be sussexite. The sussexite occurs in the veinlets as irregular matted masses of fibers with the fibers lying parallel to the plane of the vein. These veins run through both the red "soft ore" hematite and the highly altered and porous cherty gangue. The gangue separates easily from the veins leaving thin sheets of the felted fibers of sussexite. Small cavities or vugs within the veins are lined with yellow, transparent crystals of seamanite and in many instances they are implanted directly upon the sussexite. All the specimens in our possession were collected for the seamanite although the sussexite is by far the more prevalent mineral.

Sussexite has a hardness of 3+ and a specific gravity of 3.0 to 3.1. It is slowly soluble in cold concentrated mineral acids and in hot dilute acids. The elongation is negative, extinction parallel, and the indices of refraction for sodium light are: $\alpha = 1.642$, $\beta = 1.713$, and $\gamma = 1.721$ (all ± 0.003). The fibers are flattened so that most of them yield α and β. Those resting on an edge give γ and exhibit a pronounced color dispersion which is greater than that of the methylene iodide mixtures used for the index determinations.

The analysis given in Table 1 was made upon selected material which was crushed and washed with cold dilute hydrochloric acid to remove small acicular crystals of seamanite and microscopic cube-like rhombohedrons of calcite. Boron was determined by titration in the presence of mannitol, and the other oxides by ordinary gravimetric methods. $H_2O+110°$ was determined by the direct method recommended by Penfield using separate samples of approximately one gram each. It is interesting to point out that

$H_2O+110°$ was also determined by ignition in a covered crucible, the samples however changed to a black color due to the oxidation of the manganese. The two samples gave values which were 0.46 and 0.38 per cent lower than the average values obtained by the Penfield method, which may be attributed to an increase in weight due to the oxidation of the manganese. The two samples upon which the direct method was used checked to 0.05 per cent.

In measuring the indices of refraction slight variations were found in the indices of the material chosen from different veinlets. Manganese determinations made upon these samples showed a variation in MnO content from 38 to 42 per cent. The analysis given in Table 1 represents, then, cnly the composition of the particular vein from which the sample was selected and is slightly higher than the mean value for MnO. The indices of refraction given are those of the analyzed material.

Table 1

Insoluble	0.69
SiO_2	0.89
MnO	40.42
MgO	14.57
CaO	0.35
$Fe_2O_3+Al_2O_3$	0.29
B_2O_3	33.24
$H_2O+110°$	8.91
	99.36

$$\left.\begin{matrix}\mathrm{MnO}\\\mathrm{MgO}\\\mathrm{CaO}\end{matrix}\right\}:\mathrm{B_2O_3}:\mathrm{H_2O}$$

$$\left.\begin{matrix}1.1923\\0.7581\\0.0131\end{matrix}\right\}:1.0000:1.0420$$

$$1.9635:1.0000:1.0420$$

An *x*-ray diffraction photograph was taken by Mr. M. V. Denny of this laboratory with an eight inch camera using Mo Kα radiation. Table 2 gives a comparison of the diffraction lines of the Iron County sussexite with those obtained by Gruner[2] upon Franklin Furnace sussexite. The better diffraction pattern and the more complete optical data obtained indicates that the material from Iron County is better crystallized than was the Franklin Furnace specimen. Diffraction patterns taken from two specimens of material from our museum labelled sussexite from Franklin Furnace showed that neither of these specimens is sussexite.

In the last three years three borate minerals have been reported from the iron ranges of Michigan—seamanite, magnesiosussexite,[3] and sussexite. This region has never been examined to any extent mineralogically and such an examination should reveal further evidence of hydrothermal mineralization. In the past few years the question of the possible hydrothermal leaching of silica and the resultant concentration of iron ores has become quite controversial. The exponents of leaching by the downward movement of surface waters have used the supposed absence of hydrothermal minerals[4] as an argument against hydrothermal leaching. These borates are of a type that would escape casual observation or might even pass as veinlets of gypsum or some other common fibrous mineral. Our present state of knowledge permits no conclusions to be drawn as to the abundance or distribution of these minerals, and until we know more of the mineralogy of the iron districts no conclusions should be drawn as to the relationship of hydrothermal minerals to the problem of the origin of the iron ores of Michigan.

TABLE 2

Iron County	Franklin Furnace
3.33 w	
3.11 w	
2.89 w	
2.74 s	2.70 m
2.66 w	
2.61 w	2.60 w
2.46 m	2.45 m
2.40 m	
2.25 w	2.24 vw
2.14 s	2.10 vw
2.045 m	2.023 vw
1.860 w	
1.775 m	1.763 w
1.735 m	
1.600 m	
1.540 m	1.535 vw

Values in Å

Intensities s = strong
m = medium
w = weak
vw = very weak

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[2] Gruner, J. W., Magnesiosussexite, a new mineral from a Michigan iron mine, isomorphous with sussexite and camsellite: *Am. Mineral.*, vol. **17**, p. 509, 1932.

[3] Gruner, J. W., *ibid.*

[4] Leith, C. K., Secondary concentration of Lake Superior iron ores: *Econ. Geology*, vol. **26**, pp. 282–3, 1931.

A COMPARISON OF ULTRA VIOLET SOURCES FOR PRODUCING FLUORESCENCE IN MINERALS

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ABSTRACT

The properties of several sources of ultra violet light are compared as to intensity and wave lengths. Curves giving the radiation characteristics of various sources, and the transmission characteristics of certain filters are included.

One of the most interesting and spectacular of the properties of minerals is displayed in the phenomenon of fluorescence. Recently interest in this subject seems to have been particularly stimulated by the introduction of new sources of exciting radiation capable of producing fluorescence in a variety of minerals. The writer has been interested in comparing the characteristics of the various energy radiating devices available for studying fluorescence, and it is believed that such a comparison should be useful to others who are interested in these phenomena.

There are three general types of radiant energy which have been used to excite fluorescence in minerals. Cathode rays, which consist of electrons moving at extremely high velocities, produce fluorescence in a number of substances, but there are a number of practical difficulties connected with their use. *X*-rays, which are electro-magnetic waves of very high frequency, cause fluorescence in a number of minerals, but devices for producing them are expensive and the number of minerals that respond to them is limited. The most spectacular effects of all are produced by ultra violet light, that is to say light of shorter wave length than the visible range. For practical purposes ultra violet includes all light from the limit of the visible spectrum at about 4000 A.U. down to 1600 A.U., which is the shortest wave length transmitted through air until we reach the region of the *x*-rays. The visible spectrum extends from about 4000 A.U. to about 7500 A.U.

Fluorescent minerals display very wide differences in the manner in which they react toward different sources of excitation. A certain specimen of willemite from Franklin Furnace, N. J., fluoresced strongly under ultra violet of all wave lengths from 3900 A.U. down to the *x*-ray region. Another specimen of the same mineral, from the same locality, did not respond at all to wave lengths longer than 3100 A.U., but fluoresced very brilliantly under shorter wave lengths including *x*-rays. A specimen of wernerite from Quebec did not respond at all to any wave lengths shorter than 2950 A.U., and showed its maximum response in the region of 3600 A.U. This wernerite responded rather feebly to a weak light source, but responded very strongly to a moderately intense source. On the other hand, certain fluorites respond strongly to quite weak sources.

There are at the present time five primary sources of ultra violet light which are useful in the production of fluorescence. They are the argon bulb, the high potential iron spark, the iron arc, the mercury vapor lamp, and the carbon arc fitted with special cored carbons. Of these the first two give off so little visible light that they may be used without a filter. The last three must be used with a suitable filter, which is either separate or incorporated in the lamp, which removes most of the visible light and incidentally much of the useful ultra violet. As a matter of fact none of these sources is ideal from all standpoints and each has its special advantages.

The most important characteristics of an energy source are the range of wave lengths available for producing fluorescence, and the intensity of the source within this range. There seems to be little advantage in increasing the intensity above a certain optimum value, but it is absolutely necessary to have suitable wave lengths available in order to get any effect at all. Curves are presented herewith which show energy distribution at different wave lengths for various ultra violet sources. These spectra actually consist of separate lines but for convenience in representation are drawn as smooth curves. The curves do not show the relative intensity of the various sources because the differences in intensity are too great to be satisfactorily represented by curves to scale. A table giving a comparison of intensities is presented later in this paper. Curves are also given to show the transmission characteristics of certain filters which may be used to screen out visible light which would otherwise obscure the fluorescent effect. Unfortunately the best available filters transmit a rather limited range in the ultra violet. These curves used in conjunction with the table of intensity comparisons will enable the reader to evaluate the properties of any of the sources mentioned.

The argon bulb is a gas discharge tube similar in principle to the familiar neon sign tube, except that it is filled with argon and operates on the ordinary 110 volt circuit. It produces wave lengths in the long ultra violet region which are limited in the short wave lengths by the ability of the glass bulb to transmit short waves. The intensity is very low, being only about 1/2000 that of a suitably filtered quartz tube mercury lamp. However, it is cheap and easily available and produces striking effects in a number of minerals.

The term iron arc is properly applied to a low voltage arc between iron electrodes. However, mineralogists have been in the habit of using the term to refer to the high potential disruptive spark between iron electrodes which has been a popular source of ultra violet. The apparatus for producing the iron spark consists of a step-up transformer delivering about 4000 volts, a suitable condenser, and a pair of adjustable iron electrodes. As shown on the curve the iron spark produces a peak at about 2600 A.U. and is quite weak in the long ultra violet. An apparatus rated by the manufacturer at 200 watts gave about 60 times the intensity of the argon bulb. The rather large amount of visible light could not be filtered out to good advantage because available filters shut out much of the particular part of the spectrum in which the iron spark is richest. A true iron arc may be operated on direct current with about 50 volts across the arc and drawing in the neighborhood of 5 amperes. It cannot be satisfactorily operated on alternating current. It produces a considerably higher intensity than the aforementioned iron spark device but the amount of visible light produced is so great that a filter is indispensable. However, the intensity even with the filter is about twice that of the iron spark. The iron spectrum is particularly useful because of its richness in the shorter ultra violet region which produces fluorescence in a number of minerals which do not respond to most other sources. The iron spark has the particular advantage that one may dispense with a filter.

The carbon arc using special cored carbons (type "C" furnished by the National Carbon Co.) is capable of producing very powerful radiations throughout the ultra violet region. Its spectrum is strongest in the near ultra violet region but is amply powerful down to the limit of the transmission of available filters. A very large amount of visible light and a great deal of heat are also liberated. It is of course necessary to filter out the visible radiation, Corning No. 986 being the best available filter. The disadvantages are the heating effect which is likely to break the filter and the necessity for keeping the arc in adjustment. An arc consuming 11

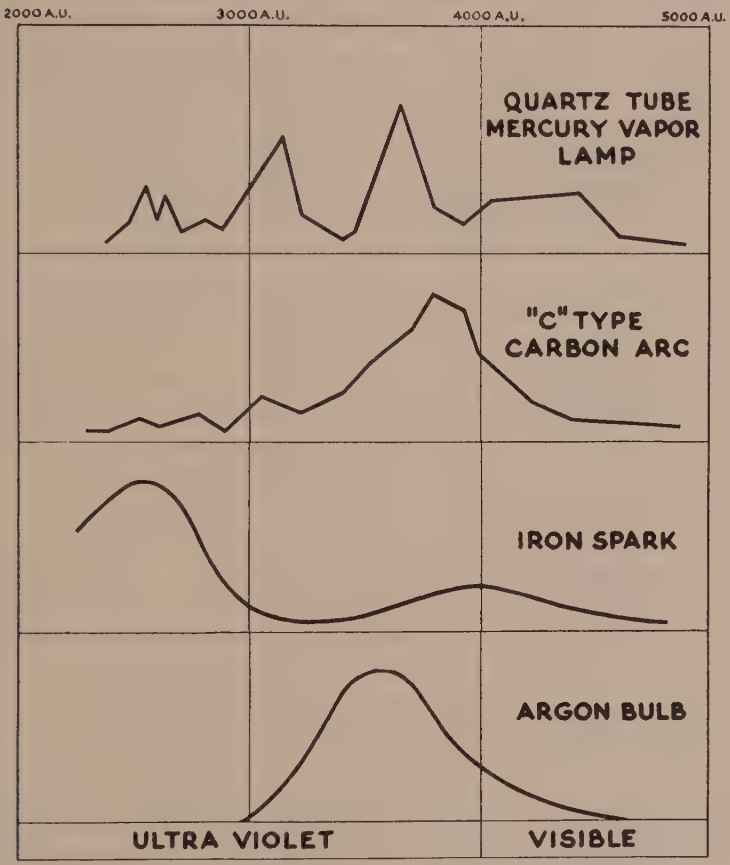

FIG. 1. Curves showing the spectra of ultra violet sources.

amperes at 50 volts across the arc furnishes satisfactory strength. If greater intensity is desired one may simply use larger carbons and greater current.

Mercury vapor lamps furnish a very powerful and convenient source of ultra violet. The visible light is so strong however that it must be filtered out by some means. If glass is used for the tube in which the arc operates, the short ultra violet is of course absorbed by the glass. The most efficient device is the mercury arc in a fused quartz tube. If filtered with the Corning No. 986 filter it furnished powerful radiations as low as 2530 A.U. in wave length which includes the range in which most minerals fluoresce. The disadvantage is the high cost of the quartz tube lamp.

There are now available two types of mercury vapor lamps in which the enclosing tube is made of special nickel-cobalt glass which eliminates most of the visible light except just within the limit of the visible spectrum. Unfortunately this glass also cuts out nearly all of the radiation shorter than 3100 A.U. and there are quite a number of minerals that respond only to radiations beyond this range. One type of lamp embodying this principle is a regular Cooper Hewitt tube 22 to 50 inches in length as desired (manufactured by the General Electric Co. and sold under the name NiCo lamp) which operates at from 250 to 450 watts. This provides radiation of ample intensity within the range of transmissibility of the nickel cobalt glass used and while the wave length range is limited it is probably the best instrument available for museum use because of its convenience. Another somewhat similar device is a mercury vapor bulb (manufacturered by Westinghouse Lamp Co. and sold under the name Black Bulb) containing a heating filament, and similar to the bulbs used in certain types of "sun lamps" used in homes, except that instead of clear glass the bulb is made of nickel-cobalt glass. The wave length range is the same as that of the device just mentioned but the power consumption for the five ampere lamp is only 85 watts and the intensity is necessarily lower.

There are a number of different glasses available which are capable of filtering out most of the visible light and at the same time letting through some of the ultra violet.[1] Of these the transmission curves of three types are here given. The best of the available filters is no doubt the Red Purple Corex A No. 986, manufactured by the Corning Glass Works. This filter transmits ultra violet down to 2500 A.U. wave length and passes only a small range in the blue end of the visible spectrum. It does transmit also a small band in the extreme red (not shown on the curve), but this does not detract from the effects especially when used with the quartz tube mercury lamp which is weak in the red end of the spectrum. This filter is rather expensive and is very liable to breakage. It is non-heat-resisting and has low mechanical strength. However, if care is taken to avoid over heating it is very satisfactory. Corning Glass Works' Red Purple Ultra No. 597 transmits a much more restricted range of wave lengths, but it is less expensive and has superior mechanical properties. The curve is also

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[1] W. S. Andrews in an article called "An Apparatus for Separating Visible From Invisible Light" in the *General Electric Review*, October, 1917, suggested a very interesting method for separating out the visible light from the iron spark radiation

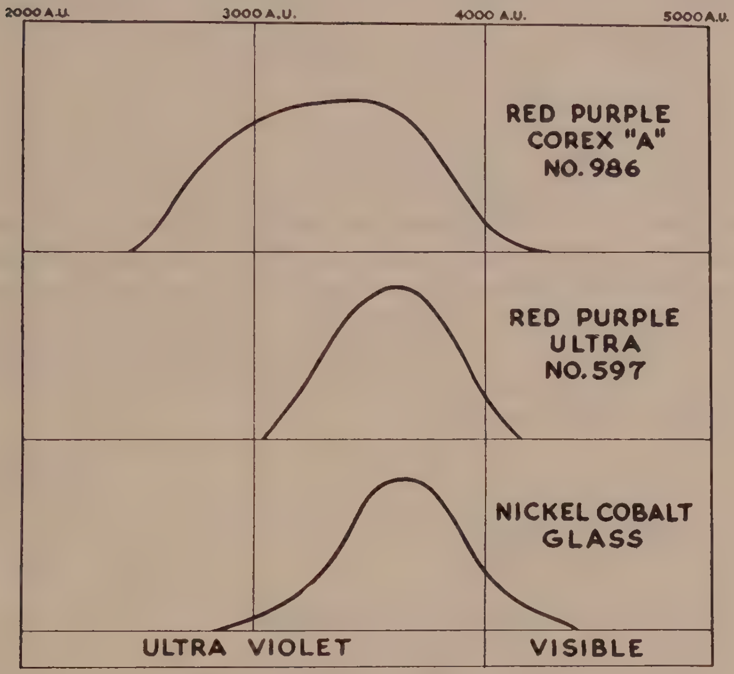

Fig. 2. Transmission curves of ultra violet filters.

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which might interest some readers. His device makes use of dispersion through a quartz lens.

given for the Nickel-Cobalt glass used for the tube in special types of mercury vapor lamps. Its range is nearly the same as that of the Corning No. 597 but it transmits somewhat more visible light. Jenaer Glaswek, Schott und Gen., Jena, Germany, manufacture a filter, type UG2, which transmits wave lengths from 4000 A.U. down to about 2850 A.U., according to their catalog. The curve for this glass is not included but it is mentioned for the convenience of European readers. The characteristics of all these glasses vary from batch to batch but the curves are believed to be representative.

The following comparisons of intensity were made by illuminating a ground quartz disc by a given source at a standard distance. The disc was then photographed using a pin hold for a lens and the density of the silver deposit on the film measured on a microphotometer. The time of exposure required to produce a definite density of image for the different sources was used as a measure of the relative intensity. The intensity of all these sources is somewhat variable under different conditions and while the comparisons are not exact it is believed that they are within the range of variation of the various sources.

SOURCE	RELATIVE INTENSITY
Quartz tube mercury vapor lamp, 4.6 amperes at 60 volts D.C. across the arc, filtered through Corning No. 986 Red Purple Corex A.	1000
Same as above Filtered through Corning No. 597 Red Purple Ultra.	600
Bulb type mercury vapor lamp (Black Bulb), 5.2 amperes at 16 volts A.C. made of nickel-cobalt glass.	45
Tube type mercury lamp (NiCo Lamp), with nickel cobalt glass tube. Rated 385 watts D.C. or 450 watts A.C.	300–350 (estimated)
Carbon arc, 12 amperes at 40 volts A.C. across the arc. Eveready "C" type carbons and Corning No. 986 filter.	500
Same as above, Filtered through Corning No. 597 filter.	360
Iron arc, 5 amperes at 45 volts D.C. across the arc, Corning No. 986 filter.	30
Iron spark, Rated at 200 watts, 4000–5000 volts, no filter.	15
Argon bulb, Rated at 2 watts A.C., no filter.	0.25

To summarize one may say that either a quartz tube mercury lamp or a carbon arc with "C" type carbons, combined with the Corning No. 986 filter, is the most generally useful ultra violet source because they combine high intensity with a great range of wave lengths. The mercury lamp with nickel-cobalt glass tube is desirable in museums because of its convenient form and freedom of adjustments. The iron spark still furnishes a convenient source of the very short wave lengths although the intensity is rather low. The argon bulb is recommended within its limits because of its convenience and cheapness.

Acknowledgments

The data used in this comparison study were partly derived from information supplied by manufacturers. However, they have been checked carefully by spectrographs and photographic intensity comparisons. Thanks is due to Professor C. D. Hodgman of Case School of Applied Science for advice and for the use of special apparatus.

HEAVY MINERALS IN THE TERTIARY INTRUSIVES OF CENTRAL COLORADO

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Introduction

The Tertiary intrusives of Central Colorado have interested geologists and prospectors since the early mining days in this region when it was found that quartz veins and copper carbonate ores were commonly associated with the igneous rocks. A relationship between the ore deposits and the intrusives was recognized in various districts but it was not until Crawford's excellent paper in 1924[1] that an attempt was made to trace the mineralizing igneous rocks in all of the surrounding districts to a common source in the large Tertiary massive—the Princeton batholith.

During the summers of 1931–1932, field parties from Northwestern University, with the co-operation of the U. S. Geological Survey, have been engaged in mapping the pre-Cambrian formations of the Sawatch Range. In connection with this work heavy mineral analyses of small granite areas of uncertain age have proven fairly successful in correlating them to one or the other of the two main pre-Cambrian batholithic intrusions of the region.[2] Similar analyses of the post-Cambrian intrusives were made at this time, and as the Princeton batholith, as well as several of the smaller outcrops studied by Crawford, occur within the Sawatch Range, it was decided to extend the work on heavy minerals to include all of the Tertiary rocks mentioned by Crawford.

The value of such analyses is readily apparent. Work on heavy minerals of the igneous rocks is still in the experimental stage. Should the mineral associations shown by these analyses agree with Crawford's conclusions based on petrographic studies, the value of this comparatively rapid means of making correlations is strengthened. On the other hand, it offers an entirely different approach to the problem of correlation of the Tertiary intrusives and in case of agreement with other methods, offers support to the previous correlation—that the various, widely separated outcrops have a common origin with the Princeton batholith.

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[1] Crawford, R. D., A Contribution to the Igneous Geology of Central Colorado: *Am. Jour. Sci.*, 5th ser., vol. **7**, pp. 365–388, 1924.

[2] Report of the Committee on Accessory Minerals of Crystalline Rocks, National Research Council, *Ann. Rept.*, pp. 2–5, **1932.**

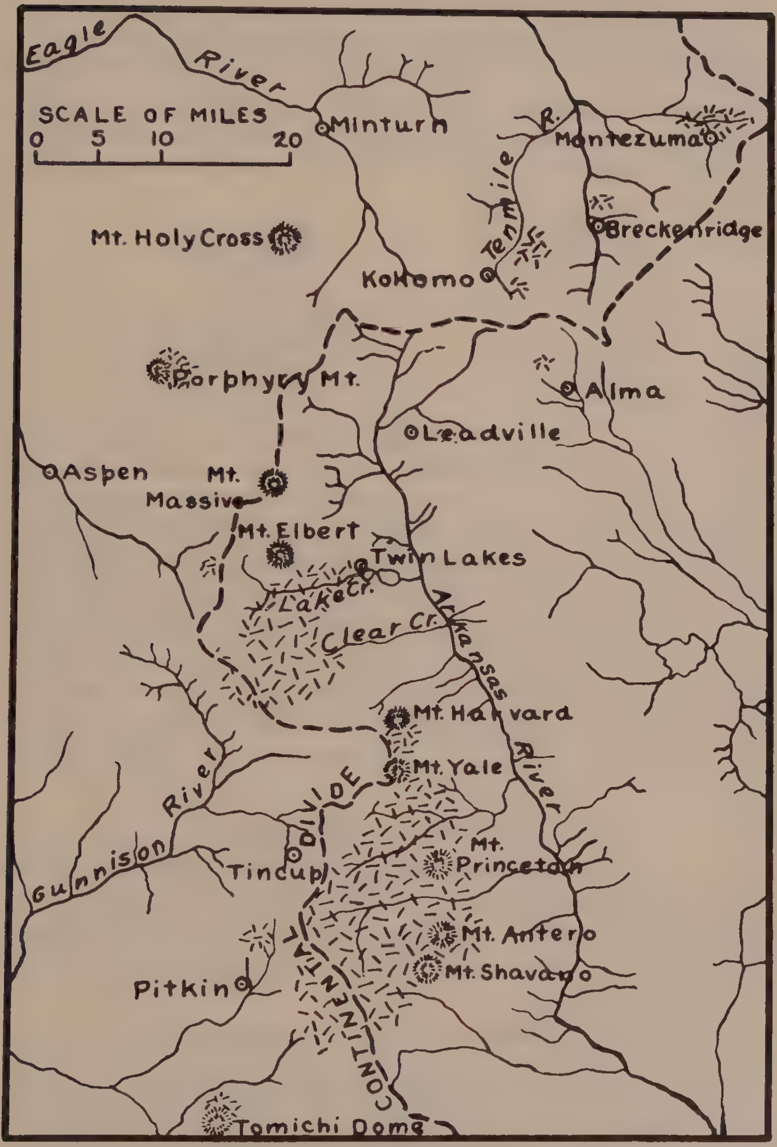

FIG. 1. Sketch map showing distribution of Tertiary intrusives. (After Crawford.)

Methods of Separation

In Figure 1, after Crawford, the outcrops of the igneous rocks, presumably of Tertiary age, are shown. To those mentioned by Crawford have been added a few new outcrops discovered in the course of the mapping in the Sawatch Range. Specimens were collected from the following localities, all of which are indicated on the sketch map:

Breckenridge
Alma
Montezuma
Leadville
Ten Mile Creek
Twin Lakes
Clear Creek
Mount Princeton
Mount Antero
Mount Yale
Tomichi Dome
Red Mountain Creek
Crested Butte
South Fork Lake Creek

Specimens approximately 4 by 4 inches were crushed to pass a 100-mesh and not a 200-mesh sieve. The heavy minerals were then separated by the use of bromoform of gravity of 2.84. The percentages of the heavy minerals in the rock specimens are shown in column I of Table I. Magnetite was removed from the separates by means of a horseshoe magnet with a thin paper collar. The ratio of magnetite to the other heavy minerals is shown in columns II and III of Table I. The remaining heavy minerals, after the separation of magnetite, were mounted in Canada balsam and studied under the polarizing microscope. Sixteen to twenty separate counts were made on each specimen and the averages in percentages are given in Table II.

Discussion of the Tables

Nine specimens are from the Princeton batholith. These were selected in traverses across the outcrop to represent peripheral as well as central zones. The other specimens are from twenty different localities, an attempt being made in each case to select fresh, representative rock.

A general survey of the tables reveals a surprising lack of variety in the heavy minerals, the same few being repeated in nearly all of the analyses. Such minerals are apatite, biotite, ilmenite, titanite, and zircon. Hornblende is represented in all but four. Epidote, pyrite, and hematite occur in a few and are probably secondary. The large amounts of pistachite in T-23, T-27, and T-35 are apparently after hornblende and might be added to the hornblende percentages.

The second striking fact brought out by the analyses is the lack of such minerals as tourmaline, monazite, fluorite, beryl, and sillimanite, all of which have been reported from the igneous rocks of the Front Range in Colorado by Mrs. Boos.[3] Their absence in the more massive facies of the Tertiary intrusives supports the early impression that these rocks were lean in mineralizers or relatively dry magmas. In this respect the Tertiary intrusives are very different from the pre-Cambrian batholiths of the Sawatch

Table I. Percentage of Magnetite in Heavy Mineral Separates

		I Total heavy minerals in specimen	II Magnetite	III Other heavy minerals
T-1	Twin Lakes porphyry, Clear Creek	0.173	75.72	24.28
T-2	Lincoln porphyry, Evans Gulch	0.113	24.77	75.23
T-3	Princeton batholith, St. Elmo	1.640	50.43	49.57
T-6	Princeton batholith, E. of St. Elmo	1.684	60.45	39.55
T-8	Princeton batholith, E. of St. Elmo	1.962	45.38	54.62
T-10	Princeton batholith, E. of St. Elmo	2.000	66.25	33.75
T-12	Princeton batholith, M. Cottonwood Creek	0.983	72.43	27.57
T-14	Princeton batholith, S. slope Mt. Yale	0.253	83.01	16.99
T-17	Princeton batholith, E. slope Mt. Yale	1.451	59.95	40.05
T-20	Princeton batholith, W. of St. Elmo	1.042	61.17	38.83
C-111	Princeton batholith, S. Cottonwood Creek	1.021	93.00	7.00
T-21	Tomichi Dome	0.289	69.88	30.12
T-23	Gray porphyry, Mosquito Creek	0.493	32.53	67.47
T-26	Quartz Creek porphyry	2.431	54.81	45.19
T-27	Twin Lakes porphyry, Red Mt. Creek	0.285	75.44	24.56
T-28	Lincoln porphyry, South fork of Lake Ck.	1.090	84.40	15.60
T-29	Montezuma	0.813	80.19	19.81
T-30	Montezuma	0.885	79.09	20.91
T-31	Breckenridge red granite	0.849	8.94	91.06
T-32	Buckskin Gulch gray porphyry	2.118	55.57	44.43
T-33	Breckenridge coarse porphyry	0.253	83.00	17.00
T-34	Lincoln porphyry, Buckskin Gulch	0.396	89.89	10.11
T-35	Lincoln porphyry, NE. Breckenridge	0.640	75.00	25.00
T-41	Lincoln porphyry, Kokomo	0.897	82.72	17.28
T-43	Granite, Kokomo	0.309	94.49	5.51
T-44	Lincoln porphyry, NE. of Leadville	0.318	91.81	18.19
T-45	Crested Butte	0.430	25.65	74.35
T-46	Porphyry Mountain	0.049	36.46	63.54

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[3] *Idem.* pp. 6–7.

TABLE II. PERCENTAGE OF MINERALS IN HEAVY MINERAL SEPARATES EXCLUSIVE OF MAGNETITE

		Apatite	Biotite	Ilmenite	Pyrite	Titanite	Zircon	Hornblende	Allanite	Pistachite	Garnet	Hematite	Topaz
T-1	Twin Lakes porphyry, Clear Creek	14.75	36.40	3.50		33.76	2.76	6.20	0.73	1.90			
T-2	Lincoln porphyry, Evans Gulch	11.26		3.97	8.06	75.96	0.75						
T-3	Princeton batholith, St. Elmo	6.21	7.32	2.83		21.77	1.70	60.17					
T-6	Princeton batholith, E. of St. Elmo	5.00	7.07	1.64		19.34	0.75	66.20					
T-8	Princeton batholith, E. of St. Elmo	2.34	2.08	12.85		25.14	2.40	53.50	1.69				
T-10	Princeton batholith, E. of St. Elmo	2.95	8.79	2.75		24.09	1.74	59.14	0.54				
T-12	Princeton batholith, M. Cottonwood Creek	5.42	9.12	0.90		36.32	3.52	44.62		0.10			
T-14	Princeton batholith, S. slope Mt. Yale	4.46	9.88	72.17		8.32	1.73	2.46		0.37	0.07	0.54	
T-17	Princeton batholith, E. slope Mt. Yale	2.65	27.08	0.93		19.68	1.01	48.65					
T-20	Princeton batholith, W. of St. Elmo	4.95	1.60	0.73		41.09	2.20	49.43					
C-111	Princeton batholith, S. Cottonwood Creek	3.83		2.31	0.25	59.65	28.06	5.90					
T-21	Tomichi Dome	3.77		8.49		6.60		3.79			16.03		61.32
T-23	Gray porphyry, Mosquito Creek	2.94	0.29	11.69		56.16	0.59	0.59		27.74			
T-26	Quartz Creek porphyry	2.92	4.63	3.02		3.93	0.20	85.30					
T-27	Twin Lakes porphyry, Red Mt. Creek	5.61		70.97	1.09	12.80	2.32	0.48		5.63	0.73	0.37	
T-28	Lincoln porphyry, South fork of Lake Ck.	12.24	35.40	3.63		36.61	2.18	9.58			0.36		
T-29	Montezuma	6.43	3.93	0.43		72.22	3.80	11.11	2.08				
T-30	Montezuma	5.66	33.02			47.89	2.91	10.52					
T-31	Breckenridge, red granite	0.64	0.32	8.42		83.83	2.91	3.88					
T-32	Buckskin Gulch, gray porphyry	6.38	2.69			12.90	1.20	76.83					
T-33	Breckenridge, coarse porphyry	13.82	2.63	71.05			10.53		1.97				
T-34	Lincoln porphyry, Buckskin Gulch	51.65	10.15	24.13		10.42	3.65						
T-35	Lincoln porphyry, NE. Breckenridge	9.92		7.94		47.64	1.49	26.06	1.49	5.46			
T-41	Lincoln porphyry, Kokomo	48.20	15.11	1.70		30.86	3.38	0.75					
T-43	Granite, Kokomo	30.31		11.06		45.78	12.41	0.44					
T-44	Lincoln porphyry, NE. of Leadville	69.97	5.26	8.23		9.10	5.92	0.76					
T-45	Crested Butte	7.59		0.64	82.59	7.42	1.12			0.64			
T-46	Porphyry Mountain	12.20	1.00	6.60		32.40	1.80	39.80	4.00	1.60		0.60	

Range which show abundant evidence in their field relations and in the heavy mineral analyses of being wet magmas.

In a general way the analyses show both a positive and negative similarity between the main mass of the Princeton batholith and the igneous intrusions of the surrounding districts, and, therefore, are not contradictory to the interpretation by Crawford that the intrusions may have had a common source with the Princeton massive. But on the other hand, from the evidence of the tables alone, the basis for such an assumption is scarcely more than suggestive.

In Table II, which gives the percentages of the heavy minerals other than magnetite, attention is called to the following points. Low percentages of ilmenite show in three specimens (T-12, T-14, and T-20) from the peripheral zone of the Princeton massive, whereas T-10, T-12, and T-20, from the same zone, show high percentages of titanite. In other specimens this general ratio of ilmenite to titanite is observed: in T-2 and T-41 from the Breckenridge district, in T-2 and T-41 from outcrops of the Lincoln porphyry, east and northeast of Leadville, in T-32 from Buckskin Gulch, and in T-29 and T-30 from the Montezuma district.

Zircon is present in nearly all of the analyses but T-21 from Tomichi Dome, which will be discussed later. The zircon percentage is seldom less than one or more than four, although notable increases occur in T-33, a coarse porphyry from Breckenridge; and C-111, the Princeton granite near Antero Springs.

Apatite is fairly constant in specimens from the Princeton batholith, ranging between 2.34 and 6.21 per cent. In most of the specimens from the surrounding districts it is much higher, rising above 45 per cent in analyses from the Lincoln porphyry.

Biotite and hornblende show considerable variation in the specimens from the Princeton batholith and those from the surrounding districts. There is, moreover, a general relationship between the two minerals showing high hornblende percentage and a low biotite percentage, or with high biotite a corresponding low hornblende percentage. Such an inference should not be given too much weight, however, in view of the limited number of analyses.

In specimen T-21, from Tomichi Dome, the distribution of the heavy mineral percentages is exceptional. The rock is a fine grained asphanite with only a few, widely scattered phenocrysts. The analysis differs from all others in that a large percentage of the heavy minerals other than magnetite consists of topaz and garnet. This was checked by oil immersion methods and in thin sections.

CONCLUSIONS

Heavy mineral analyses of igneous intrusions from twenty-nine localities show a similarity in the limited variety of the minerals and in the lack of such minerals as tourmaline, monazite, fluorite, beryl, and sillimanite, all of which have been reported from igneous rocks of the Front Range. Nine of the specimens are from traverses across the Princeton batholith and the others from various surrounding districts. R. D. Crawford, on the basis of petrographic studies and field relations, suggested that all of these intrusions were probably related to a common magmatic source. The heavy mineral analyses given in the above tables are in no way incompatible with this interpretation and may lend some support to such a correlation.

It is fully realized that the number of analyses is far too small to justify any conclusions based on the tables alone, other than the most generally suggestive or corroborative assumptions. As the work was auxiliary to the pre-Cambrian mapping, time did not permit a more comprehensive study. The data here presented is offered for what it is worth in the hope that the record, although imperfect, may aid in future work along these lines.

ACKNOWLEDGMENTS

F. F. Barnes, R. S. Cannon, and Paul Averitt acted as field assistants at various times and assisted in the laboratory separations. Their help is gratefully acknowledged.

THE THEORY OF DETERMINANTS APPLIED TO CRYSTALLOGRAPHY

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An example of the usefulness of determinants in crystallography is furnished by the derivation of the equation of zone control and of its applications. The application of the elementary properties of determinants leads, moreover, to several new zonal relations.

Three faces (hkl), $(h'k'l')$, $(h''k''l'')$ lie in a zone if the three parallel planes passed through the origin intersect along the same straight line. Analytically expressed, the condition is that the three linear homogeneous equations

$$h\frac{x}{a}+k\frac{y}{b}+l\frac{z}{c}=0$$

$$h'\frac{x}{a}+k'\frac{y}{b}+l'\frac{z}{c}=0$$

$$h''\frac{x}{a}+k''\frac{y}{b}+l''\frac{z}{c}=0$$

must yield one system of solutions. This will be the case if the *coefficient determinant*[1] be equal to zero or if

$$\begin{vmatrix} h & k & l \\ h' & k' & l' \\ h'' & k'' & l'' \end{vmatrix}=0$$

for when the elements of a row are multiplied by the same factor, the determinant is multiplied by that factor.

A determinant of the 3rd order is easily expanded according to the Rule of Sarrus. The above condition becomes

$$hk'l''+kl'h''+lh'k''-lk'h''-hl'k''-kh'l''=0.$$

If expansion be effected in terms of the co-factors of the elements of the first horizontal row, the condition for tautozonality is written:

$$\begin{vmatrix} k' & l' \\ k'' & l'' \end{vmatrix} h+\begin{vmatrix} l' & h' \\ l'' & h'' \end{vmatrix} k+\begin{vmatrix} h' & k' \\ h'' & k'' \end{vmatrix} l=0.$$

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[1] A good and amply sufficient introduction to the theory of determinants and its application to the treatment of systems of linear equations is found in the first two chapters of Arnold Dresden: Solid Analytical Geometry and Determinants, 1930.

Developing and substituting

$$u=k'l''-l'k'', \quad v=l'h''-h'l'', \quad w=h'k''-k'h'',$$

it assumes the usual form:

$$uh+vk+wl=0$$

known as the *equation of zone control.*

The outlined method of derivation makes it immediately apparent why the symbol [*uvw*] of a zone defined by two intersecting faces $(h'k'l')$ and $(h''k''l'')$ can be obtained by cross-multiplying the face indices. This so-called *process of cross-multiplication*, whose magic virtues seem so mysterious to most students, is hence reduced to its proper place of a mere mnemonic rule.

LAWS OF ADDITION AND SUBTRACTION[2]

(1) *The faces* $(h'+h''\cdot k'+k''\cdot l'+l'')$ *and* $(h'-h''\cdot k'-k''\cdot l'-l'')$ *are tautozonal with* $(h'k'l')$ *and* $(h''k''l'')$.

The proof. We have:

$$\begin{vmatrix} h'+h'' & k'+k'' & l'+l'' \\ h' & k' & l' \\ h'' & k'' & l'' \end{vmatrix} =0,$$

for this determinant is equal to the sum of two determinants,

$$\begin{vmatrix} h' \; k' \; l' \\ h' \; k' \; l' \\ h''k''l'' \end{vmatrix} \text{ and } \begin{vmatrix} h''k''l'' \\ h' \; k' \; l' \\ h''k''l'' \end{vmatrix},$$

both equal to zero as they have two parallel rows identical.

The same proof holds true if the − sign be substituted for the + sign and the word "difference" for the word "sum" in the above.

EXAMPLE: In axinite,[3] face $s(201)$ lies in a zone with $m(110)$ and $r(1\bar{1}1)$, and is also tautozonal with $M(1\bar{1}0)$ and $x(111)$. Its indices are determined by the Law of Addition.

Face $M(1\bar{1}0)$, whose indices are derived by the Law of Subtraction from those of $s(201)$ and $x(111)$, lies in a zone with s and x.

(2) *The faces* $(mh'+nh''\cdot mk'+nk''\cdot ml'+nl'')$ *and* $(mh'-nh''\cdot mk'-nk''\cdot ml'-nl'')$ *are tautozonal with* $(h'k'l')$ *and* $(h''k''l'')$, *where* m *and* n *will usually be simple integers owing to the restrictions of the Law of Haüy.*

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[2] See Rogers, A. F., *Am. Mineral.*, vol. **11**, p. 303, 1926.

[3] The orientation and axial elements adopted here for axinite are those given by Dana.

The proof. Let

$$D=\begin{vmatrix} mh'\pm nh'' & mk'\pm nk'' & ml'\pm nl'' \\ h' & k' & l' \\ h'' & k'' & l'' \end{vmatrix}$$

where the elements of the first horizontal row are taken with + signs or − signs only. We may write

$$D=m\begin{vmatrix} h' & k' & l' \\ h' & k' & l' \\ h'' & k'' & l'' \end{vmatrix}\pm n\begin{vmatrix} h'' & k'' & l'' \\ h' & k' & l' \\ h'' & k'' & l'' \end{vmatrix}=0.$$

EXAMPLE: In axinite, twice the indices of $m(110)$, plus the indices of $z(1\bar{1}2)$, yield the symbol (312) of a face W in a zone with m and z.

Twice the indices of $y(021)$, minus the indices of $r(1\bar{1}1)$, give $(\bar{1}51)$ the symbol of face q which occurs in the zone ry.

The following fact has not yet been mentioned, as far as the writer is aware: it is sufficient to know that three faces lie in a zone to be in a position to state that other groups of three faces are also tautozonal.

The value of a determinant does not change if the columns are made into lines[4] and conversely. For instance, if

$$\begin{vmatrix} h & k & l \\ h' & k' & l' \\ h'' & k'' & l'' \end{vmatrix}=0.$$

we may also write

$$\begin{vmatrix} h & h' & h'' \\ k & k' & k'' \\ l & l' & l'' \end{vmatrix}=0$$

Hence,

THEOREM A: *If three faces* (hkl), $(h'k'l')$, $(h''k''l'')$ *be tautozonal, the faces* $(hh'h'')$, $(kk'k'')$, $(ll'l'')$ *also lie in a zone.*

EXAMPLE: In axinite, the faces $h(3\bar{1}0)$, (112), $s(201)$, $g(023)$, and $e(\bar{1}11)$ all lie in zone $[\bar{1}\bar{3}2]$. Making columns into lines in the determinant yielded by the first three faces leads to faces $W(312)$, $M(\bar{1}10)$, and $y(021)$ of zone $[\bar{1}\bar{1}2]$.

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[4] Horizontal and vertical rows of a determinant are called *lines* and *columns*, respectively.

By using faces s, g, e instead, the symbols $(20\bar{1})$, $y(021)$, $\nu(131)$ are obtained: $(20\bar{1})$ is a possible face of zone $[1\bar{1}2]$ to which y and ν also belong.

The value of a determinant remains unchanged in absolute magnitude but its sign is changed when two parallel rows are interchanged.

Applying this property to two columns, we have:

Theorem B: *If three faces* (hkl), $(h'k'l')$, $(h''k''l'')$ *lie in a zone, then other groups of three tautozonal faces may be obtained by interchanging any two (but the same two) indices in the symbols of the three given faces.*

The proof. The determinants

$$\begin{vmatrix} h & l & k \\ h' & l' & k' \\ h'' & l'' & k'' \end{vmatrix}, \quad \begin{vmatrix} l & k & h \\ l' & k' & h' \\ l'' & k'' & h'' \end{vmatrix}, \quad \begin{vmatrix} k & h & l \\ k' & h' & l' \\ k'' & h'' & l'' \end{vmatrix},$$

are all three equal to zero.

It immediately follows that the symbol of the new zone will in each case be obtained by interchanging the corresponding zone indices in the symbol of the original zone. If $[uvw]$ be the symbol of the given zone, then the three zones obtained by theorem B are respectively $[uwv]$, $[wvu]$, and $[vuw]$.

Example: In axinite, faces $w(1\bar{3}0)$, $r(1\bar{1}1)$, and $y(021)$ lie in zone $[\bar{3}\bar{1}2]$. Faces $h(\bar{3}10)$, $e(\bar{1}11)$, and $s(201)$ lie in zone $[\bar{1}\bar{3}2]$.

Remarks: If two indices are equal in a zone symbol, then by interchanging corresponding indices in the face-symbol of a face in the zone, another face in the same zone is obtained. This can also be derived by inspection of the equation of zone control.

Example: In axinite, faces $s(201)$ and $i(3\bar{1}1)$ belong to zone $Ms[\bar{1}\bar{1}2]$. Faces $y(021)$ and $Y(\bar{1}31)$ also lie in the same zone.

Now by applying the theorem B twice in succession it is found that if

$$\begin{vmatrix} h & k & l \\ h' & k' & l' \\ h'' & k'' & l'' \end{vmatrix} = 0,$$

the following is also true

$$\begin{vmatrix} k & l & h \\ k' & l' & h' \\ k'' & l'' & h'' \end{vmatrix} = 0, \text{ and } \begin{vmatrix} l & h & k \\ l' & h' & k' \\ l'' & h'' & k'' \end{vmatrix} = 0.$$

Hence,

THEOREM C: *If three faces* (*hkl*), (*h*′*k*′*l*′), (*h*″*k*″*l*″) *lie in a zone, two other groups of tautozonal faces are given by the cyclic permutations of the indices in the original three face symbols.*

It is easy to see that the zone indices follow the same permutation as the face indices. If [*uvw*] be the symbol of the original zone, then the two new zones yielded by theorem C are respectively [*vwu*] and [*wuv*].

EXAMPLE: In axinite, faces *a*(100), α(210), and *m*(110) lie in zone [001]. Faces *b*(010), *y*(021), and *f*(011) lie in zone [100].

When the three zone indices are equal [111], the faces whose symbols are obtained by permuting the indices of the given faces lie in the original zone.

REMARKS: *If three faces* (*hkl*), (*h*′*k*′*l*′), (*h*″*k*″*l*″) *are known to lie in a zone, five additional groups of three tautozonal faces can be formed by applying theorems B and C to faces* (*hh*′*h*″), (*kk*′*k*″), (*ll*′*l*″).

Another proposition can be derived from the following: The value of a determinant remains unchanged when the elements of a row multiplied by a common factor are added to the elements of a parallel row.

This property applied to columns gives

THEOREM D: *If three faces* (*hkl*), (*h*′*k*′*l*′), (*h*″*k*″*l*″) *lie in a zone, then the three faces in any of the following groups are also tautozonal*:

(*Hkl*), (*H*′*k*′*l*′), and (*H*″*k*″*l*″);
(*hKl*), (*h*′*K*′*l*′), and (*h*″*K*″*l*″);
(*hkL*), (*h*′*k*′*L*′), and (*h*″*k*″*L*″);

where a capital letter (*H*, for instance) stands for the corresponding small letter (*h*) plus any multiple *m* of either one of the remaining indices (*k* or *l*). The same factor *m* must be used for the other capital letters (*H*′, *H*″) of the group, and also the same remaining index (*k*′, *k*″ or *l*′, *l*″).

The proof. We have:

$$\begin{vmatrix} h+mk & k & l \\ h'+mk' & k' & l' \\ h''+mk'' & k'' & l'' \end{vmatrix} = \begin{vmatrix} h & k & l \\ h' & k' & l' \\ h'' & k'' & l'' \end{vmatrix} + m \begin{vmatrix} k & k & l \\ k' & k' & l' \\ k'' & k'' & l'' \end{vmatrix} = 0.$$

The same proof can be adapted to all cases.

It may be of interest to derive the symbol of the zone obtained in this manner and see under what condition the new zone will be the same as the original.

Let $[uvw]$ be the symbol of the zone containing the three faces (hkl), $(h'k'l')$, $(h''k''l'')$. Let $[UVW]$ be the symbol of the zone in which $(h+mk\cdot k\cdot l)$, $(h'+mk'\cdot k'\cdot l')$, $(h''+mk''\cdot k''\cdot l'')$ are found. Expanding the above determinant we get

$$U=\begin{vmatrix} k' & l' \\ k'' & l'' \end{vmatrix}=u,\quad V=\begin{vmatrix} l' & h'+mk' \\ l'' & h''+mk'' \end{vmatrix}=v-mu,\quad W=\begin{vmatrix} h'+mk' & k' \\ h''+mk'' & k'' \end{vmatrix}=w$$

This result can readily be generalized into the following rule.

RULE: *If m times the pth index be added to the qth index in each original face symbol* (pth and qth being any two different ordinal numbers out of 1st, 2nd, and 3rd), *then the symbol of the new zone is derived from the original zone symbol by subtracting m times the qth index from the pth.*

A sufficient condition for the new zone to coincide with the original zone is that the qth index of the original zone symbol be equal to zero.

For instance, if m times the 2nd index be added to the 1st index in each face symbol of three tautozonal faces, then m times the 1st index must be subtracted from the 2nd index in the original zone symbol $[uvw]$ in order to obtain the symbol $[u\cdot v-mu\cdot w]$ of the new zone. The two zones will coincide if the original zone symbol is of the form $[Ovw]$.

It goes without saying that, in all cases, the resultant indices must be cleared of common factors if necessary and, in case m should not be chosen an integer, the indices should be cleared of common denominators.

EXAMPLE: In axinite, faces $s(201)$, $e(\bar{1}11)$, and $h(3\bar{1}0)$ lie in zone $[\bar{1}\bar{3}2]$. Take $m=-1$, let $p=2$ and $q=3$. It will be found that faces $s(201)$, $M(\bar{1}10)$, and $i(3\bar{1}1)$ lie in zone $[\bar{1}\bar{1}2]$. In the face symbols, the 2nd index is subtracted from the 3rd; in the zone symbol, the 3rd index is added to the 2nd.

It may be well to recall that to all these properties of tautozonal faces, perfectly similar properties correspond for coplanar edges on account of the known duality principle.

The starting point is the condition for three edges to be coplanar (or, in other words, for three zones to include the same face; for three zone circles to intersect in one point; for three lattice rows to lie in the same reticular plane):

$$\begin{vmatrix} u & v & w \\ u' & v' & w' \\ u'' & v'' & w'' \end{vmatrix} = 0.$$

The developments are the exact duplication of the above. They are omitted here for the sake of brevity.

Finally, one should not lose sight of the fact that the word "face" is here used in its broadest sense covering all planes (evidence of discontinuous vectorial properties) which obey Haüy's Law of Rationality: cleavage planes, twinning planes, gliding planes, x-ray "reflection" planes, as well as actual bounding faces. The meaning of the term "edge" is similarly extended: the intersection of two possible crystal planes, from the standpoint of rationality of indices.

NOTES AND NEWS

OCTAHEDRITE AS AN ALTERATION PRODUCT OF TITANITE

Frederick H. Pough, *Harvard University.*

In 1930 Dr. Hugh S. Spence of the Department of Mines of Canada described[1] a pegmatite rich in thucholite derived from uraninite from Henvey Township, Ontario. An important constituent of this pegmatite was an altered titanite intimately associated with thucholite. Dr. Spence submitted samples of this titanite to the Harvard Mineralogical Museum for examination as to the nature of its alteration, and the microscopic study of these specimens was entrusted to the author since the unusual type of alteration-product seemed to merit detailed description.

According to Dr. Spence the titanite is intimately associated with uraninite and thucholite in the centres of core-like masses of oligoclase which are distributed through the main mass of microcline. The titanite is in massive form, in aggregates of coarse crystals, pieces up to three pounds in weight having been found.

The specimens submitted are rough crystals or fragments bounded more or less by parting surfaces, the largest piece measuring 8 by 4 by 1.5 cms. They are dark green to yellowish green in color and none of them shows any of the original titanite substance. A clay-like substance not definitely determined is the main constituent of the exterior portion of the fragments and gives them their color. One fragment of the material, 4 by 3 by 1 cms. in size, is a nearly complete pseudomorph of a titanite crystal, showing the faces *c*(001), *n*(111), and *x*(102). The forms are all well developed and give excellent measurements with the contact goniometer.

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[1] A remarkable occurrence of thucholite and oil in a pegmatite dyke, Parry Sound District, Ontario. *Am. Mineral.*, vol. **15**, pp. 499–520, 1930.

The broken crystals reveal a cellular structure, consisting of a network of siliceous walls in a boxwork pattern with a distinct tendency to conform to the parting directions of the titanite. These siliceous bands are very thin, less than 1 mm., and are colored gray by intermixed clay. Upon the surfaces of these quartz septa are deposited myriads of minute black crystals of octahedrite.

The individual crystals of octahedrite are very minute, ranging from 0.16 mm. to 0.03 mm. in diameter. In ordinary light they appear quite black and lustrous, but in transmitted light they have a grayish blue color, the characteristic color of octahedrite. Several were measured on the goniometer and show only the unit bipyramid (111) in combination with the base (001). The signal from the base was poor and diffused, the face being much rounded and irregular. The pyramidal faces, though narrow, were, on the other hand, perfectly plane and gave excellent signals.

The more complete pseudomorph mentioned above was broken open to reveal its structure, and it was found that the internal appearance was somewhat different from the other specimens. Instead of having a boxwork structure, the interior was completely filled, and cleavage surfaces of calcite were noted. A fragment was allowed to stand in dilute HCl to remove the calcite, and then was found to have exactly the same appearance as the other specimens. Apparently calcite formerly filled the spaces now left as voids in most of the specimens. Within the drusy openings left after the removal of calcite, a few small, light brown, translucent, irregular crystalline fragments of rutile were found implanted on octahedrite. No rutile was found in any of the other specimens, from which the calcite was already removed naturally.

The question of the orientation of the octahedrite crystals in relation to the crystal or parting planes of the titanite was considered. It was noted that in turning the fragments so that reflections would be secured from a drusy surface, certain positions seemed to yield more brilliant reflections than the average. A study of the material under the binocular, however, failed to reveal any sort of recognizable orientation. The minute crystals of octahedrite were not confined to a single layer on the quartz septa nor were they attached in any systematic position, and it was concluded that the positions of maximum brightness were due merely to chance reflections from the multitude of tiny facets.

Although, as shown in the following summary of the literature, the formation of octahedrite as a product of the alteration of titanite has long been known, all of the previously described occurrences have been upon a microscopic scale, and in many cases the direct relationship was doubtful. In the specimens described here, this type of alteration has been observed in large titanite crystals for the first time.

The formation of octahedrite from titanite was first described by Diller[2] in 1883, who found small yellow-brown crystals of octahedrite in a hydrothermally altered granite. He assumed them to have been formed in this way because of the lack of titanite in the altered rock, although it was abundant in the original material.

The following year Thürach[3] showed more clearly that this was possible, when he found small crystals, seldom more than 0.15 mm. in diameter grown upon the walls and upon networks of limonite in spaces formerly occupied by titanite crystals. The forms observed were assumed to be a combination of the unit pyramid with the base.

Hamberg[4] infers the same origin for small crystals of octahedrite which he observed on the weathered surfaces of rutile from Kragerö. The weathering of the rutile was believed, in this case, to have resulted in the formation of titanite crystals, which, in turn, broke down to form octahedrite. He found a corroborative factor in the tendency of the octahedrite crystals to have grown on a limonitic mass, while the titanite rested directly upon the rutile. These crystals also showed a combination of the unit bipyramid with the base.

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[2] Diller, J. S., Anatas als Umwandlungsprodukt von Titanit im Biotitamphibolgranit der Troas: *Neues Jahrb.*, vol. **1,** 1883, pp. 187–193.

[3] Thürach, H., Über das Vorkommen mikroskopische Zirkone und Titanmineralien in den Gesteinen: *Ver. der phys.-med. Gesell. zur Wurzburg,* N.F., vol. **18,** Sept. 1884, p. 32.

[4] Hamberg, A.,Anatas und Titanit auf Rutil von dem Apatitvorkommen bei Kragerö in Norwegen: *Geol. Fören. Förh.*, vol. **8,** 1886, p. 473. Abstr., *Zeit. Krist.*, vol. **15,** 1888–9, p. 430.

The observations of Doss[5] were most convincing. He described crystals 0.2 to 0.02 mm. in size occupying cavities formed by the replacement of titanite, but found many transitional stages with residues of titanite, and a few fresh unaltered titanite crystals. By measurements on the microscope stage, he claimed to have determined the bipyramid (334) in combination with (001).

Lacroix[6] mentions three occurrences of octahedrite resulting from the alteration of titanite. The first is that of Saint-Marie-aux-Mines, in Alsace in Vosges Mountains. This occurrence was originally described by Müller[7] as being one of brookite, but Lacroix found upon re-examination of the specimens that the crystals were actually octahedrite, showing the unit bipyramid in combination with the base. They occurred upon the surfaces and in crevices within strongly altered titanite crystals, associated with a yellow ochreous material. A second occurrence, similar to that described by Diller, is mentioned. The crystals were scattered through diorite at Eup, near Saint-Beat, in the Upper Garonne district of the Pyrenees. A third locality is that of Grand Clot in the Alps, where dark blue octahedrite crystals occur in the midst of quartz-calcite-ripidolite geodes associated with titanite and galena. They are described as often occurring in the centers of titanite crystals. Simple unit bipyramids were found, as well as combinations of this form with the base.

Another case in which the same origin for the octahedrite has been inferred is that described by Scrivenor[8] who remarks upon the abundance of well-formed crystals of similar habit in some of the English sandstones. From the evidence he decided that the colorless crystals measuring 0.025 to 0.17 mm. must have formed in place, largely from the alteration of ilmenite grains after the deposition of the sandstone. To account for the lack of titanite, despite its abundance in the source rocks, he suggests that it has been altered to octahedrite and leucoxene.

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[5] Doss, B., Über Pseudomorphosen von Anatas nach Titanit im Syenit des Plauenschen Grundes: *Neues Jahrb.*, 1895, vol. **1**, pp. 128–138.

[6] Lacroix, A., *Miner. de France*, vol. **3**, pp. 115, 187 (1901).

[7] Müller, A., *Verh. der Naturforsch. Gesell.*, Basel, **1857**, p. 573.

[8] Scrivenor, J. B., Anatase in the Trias of Midlands: *Eng. Min. Mag.*, vol. **13**, pp. 348–351, 1903.

A NEW OCCURRENCE OF MONTROYDITE IN CALIFORNIA

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Some years ago Professor Austin F. Rogers of Stanford University described a new locality in California for the mercury oxychloride, eglestonite,[1] which heretofore had only been reported from the original locality find in the upper levels of the cinnabar deposits at Terlingua, Brewster County, Texas.[2] The California locality is situated in the foothills of the Coast Range about two miles west of Redwood City, San Mateo County, where the various mercury minerals were deposited along the joints and fissures of a pale brown siliceous rock which is a replacement of serpentine. Known as "quicksilver rock," this siliceous type of vein material is fairly common in the various mercury deposits of the Coast Range. Recently the author visited the San Mateo prospect in search of specimen material and while working on a new section of the vein about a foot below the surface, noticed groups of small, red, acicular crystals floating on drops of native mercury and in some instances lining small vugs of dolomite crystals. Examined under the microscope, these orange-red crystals proved to be montroydite, an orthorhombic mercuric oxide, which heretofore has been reported only from the original locality at Terlingua, Texas, where it was described by A. J. Moses.[3] The name montroydite was given this mineral in honor of Mr. Montroyd Sharp, one of the mine owners at Terlingua. Associated mercury minerals found in the San Mateo County deposit are eglestonite in cubic, dodecahedral, and acicular malformed crystals and also as crusts coating dolomite; calomel in masses of small colorless euhedral crystals; native mercury in drops along seams and vugs in the vein; and cinnabar in subhedral crystals and crusts. In some of the vugs there is a greenish yellow powder which suggests the mercury oxychloride, terlinguaite, but not enough of the mineral is present to make conclusive tests.

Two forms of montroydite crystals were observed:

1. Long, orange red to dark red, subhedral, prismatic forms varying in length from fractions of a millimeter to 2 mm., terminated at one end only, the other tapering down to a sharp point. These

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[1] Rogers, A. F., *Am. Jour. Sci.*, vol. **32**, p. 48, 1911.

[2] Turner, H. W., *Mining and Scientific Press*, vol. **81**, p. 64, 1900.

[3] Moses, A. J., *Am. Jour. Sci.*, vol. **93**, pp. 259–262, 1903.

showed adamantine luster, a high index of refraction, and some of the thinner crystals exhibit pleochroism from a reddish orange to a yellowish brown. They are anisotropic with parallel extinction, negative elongation, and showed cleavage parallel to the side pinacoid *b*(010). Adhering to the prisms are minute globules of native mercury and in some instances a thin film of native mercury covers entire clusters of montroydite crystals. The color varies with the thickness of the crystal, the thicker ones showing a color range from a dark red to almost black, and the thinner ones from a brilliant orange red to a yellowish brown. The exact hue of red is difficult to clearly define, but the color of massive realgar which has begun to alter to orpiment is the nearest approach to it. No specific gravity determinations were possible.

2. Malformed and bent reddish brown crystals having a worm-like appearance. These are striated, uneven and show no terminations. In some cases the crystals are so bent that they assume U-shaped forms. This is evidently bend-gliding, described by Mügge[4] and by Buerger.[5] Due to the minute size of the crystals it was not possible to determine the faces on which the striations occur and therefore to determine the direction of translation and the bending axis. As the crystals remain bent after the external forces are removed, the compression on the concave face and the tension on the convex face must be in and out of phase with each other. The above explanation may offer a solution for the bent forms exhibited by montroydite. Stibnite, kyanite, and gypsum also show very marked evidences of this type of bend-gliding. The San Mateo County montroydite was found in several bent forms similar to those described by Hillebrand and Schaller.[6]

Heated in a closed tube, the montroydite crystals melted and disappeared, leaving a sublimate of mercury a short distance above the point where the heat was applied. No trace of sulphur could be detected. Sufficient material was not available for a chemical analysis, but the theoretical percentages of the two elements composing the mineral are as follows: Hg, as the metal, 92.59 per cent; O, calculated by volume, 7.40 per cent.

Thanks are due Professor Rogers for his kind assistance in the preparation of this note.

[4] Mügge, O., Ueber Translationen und verwandte Erscheinungen in Krystallen: *Neues Jahr. f. Min.*, **1898**, I, p. 72.

[5] Buerger, M. J., *Am. Mineral.*, vol. **15**, p. 45, 1930.

[6] Hillebrand and Schaller, *Bull.* **405**, *U. S. Geol. Surv.*, pp. 47–172, 1909.

FLUID INCLUSIONS IN PYRITE

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The writer has called attention to the brine contained in the negative crystal cavities of the Joplin galena.[1] Newhouse has extended these observations to galena from this and other localities and also to sphalerite from several sources.[2,3] It is therefore of interest to note that fluid inclusions have also been observed in the ubiquitous sulfide, pyrite.

In crushing some rather perfect crystals of pyrite for chemical work, a special search was made for possible fluid inclusions among the fresh fragments resulting from the first coarse crushing. The detection of both cavities and spilled liquid is easy in galena and sphalerite, because the smooth cleavage surfaces render them obvious; it is very difficult in pyrite because of the irregular lighting effects obtained on the conchoidal fracture surface. In spite of this, both cavities and fluid were observed on a number of smooth fragments just after crushing.

Pyrite crystals from Bingham, Elba, and an unknown locality, (coarsely striated, one-inch cubes) have been examined. All show simple to complex interlineage cavities similar to those already described for galena. All also show evidence of fluid inclusions. These appear as localized films made visible on smooth surfaces because of Newton's interference fringes. These tarnish-like areas first appear as small continuous patches, later collecting into small microscopic spots, presumably as evaporation continues. In some cases, the films may be definitely seen to be localized in the regions of cavities. In most instances, however, the unevenly broken pyrite surface renders the detection of cavities near the film impossible.

The writer gained the impression from the small extent of film associated with cavities, that the cavities must be very incompletely filled with liquid. If this rather insecure observation be accepted, it suggests that the cavities in pyrite were originally gas-filled, the film now observable resulting from that part of the original gas which was capable of condensing to form liquid.

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[1] Buerger, M. J., The negative crystal cavities of certain galena and their brine content: *Am. Mineral.*, vol. **17**, pp. 228–233, 1932.

[2] Newhouse, W. H., The composition of vein solutions as shown by liquid inclusions in minerals: *Ec. Geol.*, vol. **27**, pp. 419–436, 1932.

[3] Newhouse, W. H., The temperature of formation of the Mississippi Valley lead-zinc deposits: *Ec. Geol.*, vol. **28**, pp. 744–750, 1933.

THE MINERALOGICAL SOCIETY OF AMERICA

FIFTEENTH ANNUAL MEETING

December 27–29, 1934

Rochester, New York

Program

John E. Wolff, *Presidential Address:* **The Crazy Mountains, Montana—an area of super-alkaline and sub-alkaline Tertiary intrusive rocks, and their problems.**

Preliminary List of Papers

To be presented Thursday, December 27, 1934, after the business session at 2 p.m., and on the afternoon of Friday, December 28, 1934.

M. J. Buerger—**The Silica Frame-Work Crystals and their Stability Fields.**

N. L. Bowen—**Preliminary Note on a Series of Synthetic Fluor-Amphiboles.**

T. L. Walker—**The Amber from Cedar Lake, Manitoba.**

Tom. F. W. Barth—**Synthesis, Constitution and Optical Properties of the Noselite-Haüyne Series.**

Lewis S. Ramsdell—**X-Ray data on the system** K_2SO_4-$MgSO_4$-$CaSO_4$.

R. J. Colony—**Mineralogical Observations on Silicosis.**

M. A. Peacock—**On Topaz from Devil's Head, Colorado.**

L. H. Bauer and H. Berman—**Xonotlite from Franklin, N. J.**

D. Jerome Fisher—**Crystal Classification and Symbolism.**

G. Tunell and C. J. Ksanda—**The Crystal Structure of Calaverite.**

J. J. Runner—**Morinite from Black Hills Pegmatite.**

E. P. Henderson and Jewell J. Glass—**Pyroxmangite from Idaho.**

A. H. Phillips and H. H. Hess—**Metamorphic Differentiation at Serpentine—Country Rock Contacts.**

A. F. Rogers—**The Chemical Formula and Crystal System of Alleghanyite.**

A. L. Parsons—**Linear Mineralogical Arithmetic.**

J. D. H. Donnay—**Friedel's Law of Mean Indices.**

J. F. Schairer and N. L. Bowen—**Fusion Relations of the Feldspathoids, the Alkali Feldspars and Silica.**

P. F. Kerr—**A Scheelite-Beryl Deposit at Oreana, Nevada.**

A. M. Winchell—**Further Studies in the Pyroxene Group.**

M. J. Buerger—**The Application of Plane Groups to the Interpretation of Weissenberg Photographs.**

Lewis S. Ramsdell—**A Derivation of the fourteen Bravais Space-Lattices.**

R. J. Colony—**Schiller Structure.**

M. A. Peacock—**On the Choice of Crystallographic Elements.**

Harry Berman—**Crystallography of Mullite.**

A. F. Rogers—**Use of the term Syngony in Geometrical Crystallography.**

R. H. Bray, R. E. Grim and P. F. Kerr—**Technique for the Investigation of Argillaceous Sediments.**

Duncan Stewart, Jr.—**Notes on Some Rocks from Adelie Land and the Antarctic Archipelago.**

B. M. Shaub—**Some Applications of Color Photography in Mineralogy.**

A. E. Alexander—**Differentiation of the Onondaga formation by means of heavy mineral studies.**

W. V. Howard—**Crystallographic Expression of the Results of the Theory of Space Groups.**

James S. Wishart—**Studies in the Chromite Group.**

Donald M. Fraser—**Microscopical Investigation of Friedensville Zinc Ores.**

Robert D. Butler—**Mylonitic Sphalerite from Friedensville, Pennsylvania.**

Fred Jolliffe—**A Study of Greenalite.**

L. V. Foster—**Microscope Optics.**

G. M. Yatsevitch—**On Herderite from Topsham, Maine.**

Frederick H. Pough—**New Occurrences of Phenacite.**

Duncan McConnell—**Spherulitic Concretions of Dahllite from Ishawooa, Park Co., Wyoming.**

Alfred L. Ransome—**The Occurrence of Enargite and Plumbojarosite at Picher, Oklahoma.**

Julian J. Petty—**Origin and Occurrence of Fulgurites in the Atlantic Coastal Plain.**

Ralph J. Holmes—**X-Ray Studies of Nickel-Cobalt Arsenides.**

LLOYD W. STAPLES—**Austinite, a new arsenate mineral, from Gold Hill, Utah.**

——— **Adamite from Gold Hill, Tooele Co., Utah.**

ARTHUR L. HOWLAND—**An Occurrence of Barite in the Red Beds in Colorado.**

ALFRED C. HAWKINS—**Distribution of Heavy Minerals in the Cretaceous of Middlesex County, New Jersey.**

A complete list of titles together with abstracts will be published by the Geological Society of America, and will be available for distribution in Rochester.

Headquarters and place of registration will be in the Chester Dewey Building of the River Campus, University of Rochester.

Arrangements are being made for reduced railroad rates on the certificate plan for all members of the Mineralogical Society of America and their families. Certificates will be mailed from the Secretary's office about December 1st. Be sure to fill out the identification certificate for each ticket at the time of purchase. Extra certificates will be mailed on request.

PAUL F. KERR, *Secretary*

Correction

On page 350, lines 10–12 should read: "the twin axis is $\perp(110)$ (if the crystallographic elements be taken analogous to those of mica);".

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